Chapter 6
Highways in the Sky

By 1937, Amelia Earhart, "the Queen of the Air" according to the media of the era, already had several historical firsts in her portfolio of achievements: she had been the first woman to fly solo over the Atlantic, not only once but twice, and she also held the altitude record for female pilots.

As the next step, Earhart had just recently attempted to be the first woman to fly around the world, only being immediately forced to abort her attempt due to technical issues with her airplane. But the moment the plane was repaired and ready to fly again, she restarted her attempt, this time from Oakland, California.

On July 2nd, after about a month and a half of flying and with 29 intermediate stops behind her, she had loaded her shiny *Lockheed Electra* twin engine plane up to the hilt with gasoline on a small airfield in Lae, New Guinea, and was ready to embark on the most dangerous part of her circumnavigation.

Earhart had only three legs to go until she would be back in Oakland.

Also on the plane was her sole crew member Fred Noonan, a distinguished navigator, who had helped her on her arduous eastward travel around the globe.

It had taken them 42 days to reach their current stop at Lae, and the next flight was expected to cross the first stretch of the vast emptiness of the Pacific Ocean—from Lae to the tiny, two kilometer-long and half a kilometer-wide piece of coral called Howland Island, over 4,000 kilometers and 18 flight hours away.

The size of the Pacific Ocean is hard to grasp: it covers almost a third of Earth's surface, and when seen from space, it fills almost the entire visible globe, with only a couple of tiny specs of land breaking the blue vastness of the water.

Even today, many of the islands in the Pacific don't have airports and get a visiting ship only once per month or even more rarely, so if you are looking for a place away from the hustle and bustle of the modern world, some of the remote Pacific islands should definitely be on your list.

In 1937, the existing navigation methods for crossing oceans were based on the naval tradition that had been in use for about 200 years, since John Harrison solved the problem of finding your longitude: measurements of the positions of the Sun,

P. Launiainen, *A Brief History of Everything Wireless*,
https://doi.org/10.1007/978-3-319-78910-1_6

Moon or stars are taken with a sextant and an accurate clock to get a fix on the current location.

Based on these observations, you calculated your expected compass heading, trying to compensate for the prevailing winds as well as possible, by checking the direction of waves and relying on the sparse weather reports available for the area.

Airplanes flying across vast stretches of ocean used exactly the same approach, so it was no surprise that Fred Noonan was not just a navigator but also a certified ship captain. He had recently participated in the creation of several aviation routes for the seaplanes of *Pan American Airways* across the Pacific, so tackling a challenge like this was not unfamiliar to him.

But *Electra* wasn't a seaplane, so it had to find a runway at the end of the flight, and Howland Island was the only one within range that had one.

To hit such a small target after such a long flight was very ambitious because there were only a couple of other islands along the way that could be used to verify their actual position. Thus, to alleviate this problem, the plan was to get some extra help from novel radio location technology on board U.S. Coast Guard ship *Itasca*, which was anchored at the island—*Itasca's* radio transmitter was to be used to provide a locator beam, guiding *Electra* to its destination.

Electra had a brand-new *direction-finding receiver* on board, which had been installed at Lae just prior to this flight, and this method of medium-range navigation was expected to provide a sufficient backup against any navigational errors that were caused by flying for hours over open sea.

Similarly, *Itasca* also had direction-finding equipment on board, which could be used to get a bearing on the incoming plane's transmissions, and any corrective guidance could be relayed to Earhart.

It was inevitable that after such a long flight with only a handful of physical locations for getting a reliable location fix, ending up *exactly* at Howland Island after 18 hours of flight time would be an unlikely outcome. Therefore, the help of radio navigation would be most welcome.

The idea of the *Radio Direction Finder (RDF)* system is simple: a fixed radio transmitter sends a low-frequency signal at a known point on Earth, and the receiver uses a rotating loop antenna to determine the direction of the incoming signal. At a perpendicular position to the loop, the signals received by the edges of the loop cancel each other out, and a distinctive drop in signal strength is observed. By reading the angle of the antenna at this "null position" it is possible to determine the relative bearing of the transmitting station and align the plane's heading accordingly.

The RDF system does not even require a dedicated transmitter—any radio transmitter that sends on a compatible frequency will do. Therefore, as RDF receivers became more commonplace in planes after the Second World War, strong broadcast transmitters were often used for this purpose, with the additional benefit of providing music and other entertainment for the flight crew.

But in 1937, in the middle of the Pacific, the only transmitter to be found was the one on board the *USCG Itasca*, and as expected, around the expected time of arrival, *Itasca* received ever-strengthening audio transmissions from Earhart.

She reported poor visibility due to overcast clouds and asked the *Itasca* crew to figure out the bearing of *Electra* by the audio communications she made, apparently not realizing that the RDF receiver on *Itasca* did not support the active audio transmission frequency used by Earhart—she clearly was not really familiar with this new technology. Although it was obvious from the strength of the very last received signals that the plane was indeed somewhere near to the intended destination, no two-way communication was ever achieved, for reasons unknown. Earhart even acknowledged the reception of *Itasca's* RDF beacon signal at her end, but indicated that she could not get a bearing from it, without giving any details as to why.

The last received transmission at 8:43 AM stated the assumed position and direction of the flight and that they were flying at a very low altitude, low on fuel, trying to spot any land. As a last resort, *Itasca* used the ship's boilers to generate a huge plume of smoke for Earhart to see, but there were no further transmissions received from the plane.

Electra disappeared, seemingly without a trace.

The U.S. Navy did an extensive search in the nearby areas but did not find any sign of the plane or the crew.

The final location of *Electra* and the destiny of its crew remains an unresolved mystery to this day, and the search for the remains of the crew and the hull of *Electra* still continues to make headlines at various intervals. Findings of human bones on nearby atolls have been reported, but at the time of writing this book, no confirmation of a definite match with either Earhart or Noonan has been announced.

Both crew members were officially declared dead two years after their disappearance.

The investigation into the reasons behind the failure was able to indicate several potential problems:

First, the weather was poor, and distinguishing low cumulus cloud shadows from the profile of a small island while flying can be very difficult in such a situation.

Second, the assumed position of Howland Island was found to be off by about 9 km. This is not much in aviation terms, but it could have led Noonan off course just enough during the final moments of the approach to make his target island vanish in the haze that was caused by the poor visibility. With this level of error, they could have flown past their destination, and then ended up circling over the open water surrounding Howland Island.

Perhaps the biggest mistake Earhart made, though, was the fact that she did not practice the use of her newly installed RDF equipment. She had only been given a brief introduction to the system prior to takeoff at Lae.

This may sound like deliberately asking for trouble, but from her point of view, the RDF system was only a backup measure: they had already crossed two thirds of the globe by means of traditional navigation methods, and Earhart had probably gained a false sense of confidence due to her earlier successes along the way.

Unfortunately, the leg from Lae to Howland Island was the most complicated and unforgiving part of the journey, with no room for error, and it is easy to say in hindsight that spending a bit more time familiarizing herself with this new technology could have turned a tragedy into a triumph.

This leads us to the crucial point, applicable to any of the latest, shiniest navigation equipment at our disposal: even the best equipment is worthless unless you know how to use it, and, in case of malfunction, you should always maintain a general sense of location so that you can proceed to your destination by using other means of navigation.

Always have a backup plan.

There are plenty of recent horror stories of persons blindly following the guidance of their navigation equipment, leading them sometimes hundreds of kilometers off the intended destination, or even into life-threatening situations, simply due to inaccurate mapping data or incorrect destination selection.

If this is possible with the extremely easy-to-use equipment we currently have, it is not difficult to see how Earhart could have made an error with her much more primitive setup.

RDF systems had gone through several evolutionary steps prior to ending up as auxiliary equipment on the *Electra*. The accuracy of such a system was partly dependent on the size of the loop antenna, which again was limited by the physical measures of an airplane and the extra drag an external antenna generates during flight.

Due to this, the very early systems used a reverse configuration, in which the transmitting loop antenna was rotated with a fixed speed, synchronized to a clock, and the receivers could determine their bearing from the time it took to detect the lowest level of signal.

As discussed in Chapter 3: ***Radio at War***, this type of technology was first used to guide the German *Zeppelin* airships, between 1907 and 1918, most notably during the First World War bombing raids on London.

RDF systems are quite limited in their usefulness, and improvements in electronics finally led to the current, ubiquitous *VHF Omni Range* (*VOR*) systems, which, instead of sending just a homing beacon, make it possible to determine on which particular *radial* from the VOR transmitter you currently reside.

The radial information is sent with one-degree resolution, embedded by altering the phase of the signal in relation to the transmission angle, so no mechanical movement is necessary either on the transmitter or the receiver side. The receiver only has to extract the phase information from the received signal in order to detect the current radial related to the fixed location of the VOR transmitter.

You can accurately pinpoint your position by getting radial fixes from two separate stations and drawing the corresponding lines on your aviation chart. The position on the map where these two radials cross is your current location.

Some VOR stations even contain an additional *Distance Measurement Equipment* (*DME*) setup, which allows airplanes to figure out their *slant distance*, which is the direct line distance from the airplane to the ground antenna. This allows you to get an accurate position fix from only a single VOR station.

DME is based on the same principle as *secondary radar*, which will be discussed in Chapter 12: ***"Please Identify Yourself"***, except in this case, the roles of the airplane and the *transponder* are reversed—the airplane does the polling, and the ground station responds to the query signal. The airborne receiver can then determine the slant distance by calculating the elapsed time between query and response.

The origins of DME date back to the early 1950s, when James Gerrand created the first functional system at the Division of Radiophysics of the *Commonwealth Scientific and Industrial Research Organisation* (*CSIRO*) in Australia. DME became an International Civil Aviation Organization (ICAO) standard, and it shares the same principle as the military version, *Tactical Air Navigation System* (*TACAN*).

VOR technology was first used in the United States in 1946, and it remains the backbone of current aviation navigation: *airways* crisscross the skies all around the world, based on virtual lines between *waypoints*, such as airports, VOR stations and known intersections between two fixed radials. Flight plans are constructed as sets of these waypoints, leading from one airport to another in a pre-determined fashion. These airways create highways in the sky, shared by multiple planes, separated either by altitude or horizontal distance by *Air Traffic Control* (*ATC*).

For the final approach to major airports, another radio system called *Instrument Landing System* (*ILS*) is used, and it dates back even further than VOR: the tests for an ILS system started in the United States in 1929, and the first working setup was activated at Berlin Tempelhof airport in 1932.

ILS creates a "virtual" *glideslope*, a highly directional radio signal with a small, usually three-degree vertical angle, which can be used as a guide to the beginning of the runway, both horizontally and vertically. The signal can be followed either by manually looking at the *glideslope indicator*, or automatically by an autopilot that follows the invisible electronic "downhill" towards the runway.

With this system, planes can approach the airport with zero visibility, with the aim of ending close enough to the runway to be able to finally see the runway lights before a specified *decision altitude* is reached. If there is no visual contact at this point, the plane has to perform a *missed approach*—pull up and try again by returning to the initial acquiring point of the glideslope, or give up and fly to an alternative nearby airport that reports better weather conditions.

With *Category IIIc ILS*, an autopilot with matching *autoland* capabilities can perform a complete landing without any interaction from the pilot, and in zero visibility. The first such landing happened in Bedford, England in 1964. Most modern airliners have the autoland feature in their autopilot system, and to maintain certification, it must be used at least once per 30 days, whatever the weather, so chances are that those of us who fly frequently have experienced an automatic landing at some point.

The newest radio navigation aids that have taken the world by a storm are satellite-based navigation systems.

Unfortunately, this technology was not yet available on the evening of September 1st, 1983, when *Korean Airlines* flight *KAL 007* was readying for takeoff from Anchorage, Alaska, in order to fly across the Northern Pacific Ocean to Tokyo, Japan:

The transcripts show that the flight plan of *KAL 007* had been accepted by the *Air Traffic Control* (*ATC*) "as filed", meaning that the requested flight plan that was based on the standard *Romeo 20* airway across the ocean did not need to be modified, and the expectation was that the pilots had entered it accordingly into the plane's *Inertial Navigation System* (*INS*).

In the case of *KAL 007*, this was by no means the first time this standard airway route, Romeo 20, was being flown, and everything should have been entirely routine for the experienced Korean crew.

INS has a map of global coordinates of thousands of *waypoints* in its internal database and is able to guide the autopilot of the plane based solely on the inputs from its internal *gyroscopes* and *accelerometers*, without needing help from other navigation systems. INS simply detects the physical movements of the airplane in all three dimensions, constantly calculating the expected position based on these inputs. This technology was originally developed to aid spacecraft navigation, having its origins in the feared German *V-2* rockets of the Second World War. It was adapted for aviation use in the late 1950s to help navigation in regions with no radio navigation facilities, like during long oceanic crossings around the globe—exactly what *KAL 007* was about to embark on.

The plane took off and was assigned a coarse heading according to the active flight plan, with the request to report back to the ATC when it was passing the BETHEL VOR station, near the Alaskan coastline.

The pilots entered the assigned heading into the autopilot but apparently never switched the autopilot to the INS guidance mode. The assigned initial coarse heading was close enough to the right one, though, and the crew must have been satisfied with the direction they were flying in.

KAL 007 made the required BETHEL report 20 minutes after takeoff, and the second waypoint in the flight plan, NABIE, was confirmed as the next expected mandatory reporting point. But neither the crew nor the ATC of Anchorage noticed that *KAL 007* had actually flown about 20 kilometers north of BETHEL VOR and thereafter continued flying slightly off course, on a more northerly route. As a result of this wrong heading, *KAL 007* was not going to cross over NABIE.

Despite this, the crew made the expected mandatory radio report, claiming to be over NABIE. It is unclear how the pilots came to the conclusion that they had eventually reached the NABIE waypoint, but they clearly had not been fully aware of their actual navigational situation ever since the very beginning of their flight.

The first indication that something might be wrong was due to the fact that the Anchorage ATC did not respond to their positional radio calls at NABIE, so they relayed their position reporting message via another *Korean Airlines* flight *KAL 015*. That flight had left Anchorage some 15 minutes after *KAL 007* and was listening on the same ATC frequency.

Atmospheric radio interference in high Northern latitudes is not entirely uncommon occurrence, so this glitch with relatively long-distance communications may have happened during their earlier flights as well, and thus was not necessarily seen as a major issue at the time.

But three and a half hours later, due to this undetected course deviation, *KAL 007* was already 300 kilometers off course and entered the airspace of the Soviet Union, over Kamchatka Peninsula. It ended up crossing just north of the city of

Petropavlovsk—a town facing the Northwest coast of the United States. In better visibility, the appearance of city lights along a route that was supposed to fly over open sea would have been an unmistakable warning sign, but *KAL 007* was now flying over a heavy cloud cover that dampened out any light from below.

Most unfortunately, this was all happening at the height of the Cold War, and Petropavlovsk was the home of several top-secret Soviet military installations and airports, aimed at spying on the United States and acting as the first line of defense against any military actions against the Soviet Union.

The recordings of the Soviet Air Defense indicate how this violation of airspace was immediately noticed and several fighter jets were scrambled to respond, soon approaching the plane that was about to enter the international airspace again after crossing over the full width of Kamchatka. It was a dark, cloudy night, and the Soviet fighter pilots failed to recognize the type of the plane, while actively discussing whether it could be a civilian plane.

Even though the pilots could not confirm the type of the plane and had suspicions that it may not be a military target, their controller on the ground instructed them to shoot it down: after all, there had been several earlier spy flights by the U.S. Air Force over the military installations in the area, and the commanders who had failed to respond to these incidents had been fired.

Almost at the same moment as the command to attack was given, the totally oblivious crew of *KAL 007* contacted the *Tokyo Area Control Center* and made a request to climb to flight level 350 in order to reduce fuel burn—a standard procedure when the weight of the plane had reduced enough, thanks to the diminishing amount of kerosene in the tanks.

The altitude change was granted, and as the plane started to climb, its relative horizontal speed was suddenly reduced, causing the tailing Soviet fighters to overtake it. This random change in relative speed was thought to be an evasive maneuver, further convincing the Soviet pilots that the plane really was on a military spying mission and fully aware of being followed.

The jets caught up with the jumbo again, and three minutes after *KAL 007* had made the radio call informing that they had reached the assigned flight level 350, the plane was hit by two *air-to-air missiles*.

Despite losing pressurization and three of its four hydraulic systems, *KAL 007* spiraled down for an additional twelve minutes until it crashed into the sea near Moneron Island.

A total of 269 people, passengers and crew, were killed as a result of a simple pilot error, which could have been avoided by cross-checking their course using any other navigation means that were available in a commercial airliner. There would have been many direct and indirect ways to check the position of *KAL 007*, but apparently the course felt “right enough” to the pilots, and having flown the same route several times in the past, they ended up being oblivious to the mistake they had made.

Just two weeks after this tragic incident, President Ronald Reagan announced that the *Global Positioning System* (*GPS*), a novel satellite-based navigation system that was under construction and had been designed exclusively for the U.S. Military, would be opened for free, civilian use.

The roots of a Global Positioning System go all the way to the very beginning of the *Space Race* between the Soviet Union and the United States: when the very first satellite, *Sputnik*, was launched by the Soviet Union in 1957, it proudly made its presence known to anyone who had a receiver capable of listening to the constant beeping sound at 20.005 MHz frequency.

Two physicists, William Guier and George Weiffenbach, at Johns Hopkins University, studied the frequency shift that was caused by the relative speed of the satellite against their fixed receiver: due to the *Doppler effect*, the frequency you receive appears higher than the expected frequency when the transmitter is moving towards you, and lower when it moves away from you. Based on the dynamic change of this observed shift, Guier and Weiffenbach managed to create a mathematical model that could be used to calculate *Sputnik's* exact orbit.

After some further study, they realized that this process could also be reversed: if you knew the orbit of a satellite and the exact frequency it was supposed to send on, you could use the same mathematical model to calculate your position on Earth based on the dynamically changing frequency shift that you observe. This approach is also the basis of the GPS system.

The project for the current GPS system had been started by the *U.S. Department of Defense* (*DoD*) in the early 1970s, with the first satellites launched into orbit in 1978. Although the driver for GPS was its projected military use, there had always been a provision to also offer signal for civilian use, if that was deemed necessary later in the program.

One of the most ominous military reasons for being able to derive your exact position information anywhere in the world concerned the launching of *Polaris* nuclear missiles from submarines: if the launch location was not known precisely enough, it would be impossible to feed correct trajectory data to the missiles, and they could miss their intended targets by tens, if not hundreds of kilometers.

Nuclear missiles are not the kind of weapons that you would like to resort to having such a crap shoot with.

Another driver for GPS was to provide a superior replacement for the existing ground-based navigation system called *Long Range Navigation* (*LORAN*) that had been in use since the Second World War. The available location accuracy was expected to improve from about a couple of hundred-meter range with LORAN to just a couple of meters with the military-grade signal of the GPS.

The final incarnation of LORAN, *LORAN-C*, was intended to be used for military aviation and naval navigation, but with the advent of smaller receivers, enabled by the technology switch from vacuum tubes to transistors, LORAN-C was made publicly available and it was installed even in many commercial and private airplanes during 1970s.

The issue with all generations of LORAN was the fact that it used low frequencies for its ground-based transmitters, and these frequencies are highly sensitive to ionospheric conditions. Therefore, the accuracy of LORAN varied hugely depending on the weather and time of day.

Although President Reagan's order eventually did open GPS for civilian use, it still used two different modes: a high-precision signal for the military, and another, deliberately more imprecise, *selective availability* (*SA*) signal for civilians, which randomly reduced the accuracy so that it could be off up to 100 meters at times.

Despite this intentionally degraded signal, the use of GPS spread rapidly, as even the low-quality position information was far better than anything else at a comparable cost, and the required receivers were truly portable.

The final boost for GPS happened when President Bill Clinton unleashed its full potential with an executive order in 1996. He authorized the removal of the deliberate scrambling of the civilian signal. Therefore, in May 2000, the precision of all existing GPS receivers in the world improved more than tenfold without any extra cost or software updates.

This fundamental change happened at the same time as the advances in electronics made extremely cost-effective GPS receivers possible, leading to the explosion of navigation equipment use. The integration of GPS receivers has now reached a point at which even the cheapest smartphones offer in-built navigation functionality.

The GPS system is an intricate setup, consisting of 30 active satellites, plus several standby spares ready to step in in case of a failure, together with ground stations that keep the satellites constantly up to date and monitor their performance. At any given time, at least four satellites are visible at any location on Earth, and by listening to the encoded microwave transmissions from these satellites and referencing this information to the available data specifying their expected orbits, it is possible to calculate your position anywhere on Earth. The more satellites you can receive, the better the accuracy, down to just a couple of meters.

This seemingly simple arrangement is based on some extremely complex mathematical calculations, in which the three-dimensional "signal spheres" from the satellites are matched against each other to find your exact location, and it is the invisible magic resulting from this marriage of mathematics and radio waves that helps you to realize that you just missed a crucial turn on your way from A to B.

In a GPS system, the most expensive parts, including the very accurate atomic clocks that provide nanosecond (one billionth of a second) resolution timing information for calculations, are built into the satellites. Having the most complex parts of the system embedded in the supporting infrastructure makes it possible to have GPS receivers on a microchip that costs only a few dollars. As a result, precise location detection functionality can therefore be added cheaply to almost anything that moves.

Microchips are explained in TechTalk ***Sparks and Waves***.

The GPS system initially became operational in 1978, and the first satellite of the current GPS generation was launched in 1989. With the addition of *Wide Area Augmentation System* (*WAAS*) satellites, GPS is now extremely precise. WAAS satellites send additional corrective information that helps counteract dynamically occurring signal reception errors, caused by random ionospheric disturbances.

There is an inherent limitation with basic GPS receivers when they have been powered off and moved to a new location: in order to realign itself, the receiver has to first scan the used frequencies in order to determine which satellites it is able to receive, and thereafter *download* the necessary satellite position tables, *ephemerides* and *GPS almanac*, to be able to perform any positional calculations. This data is repeatedly streamed down as part of the received signal, but as the data speed is only 50 bits per second, it may take up to 12.5 minutes until the receiver is again able to determine its location and provide a solid position fix.

TechTalk ***Size Matters*** discusses data speeds in detail.

This delay can be eliminated if there is a way to load the satellite location data tables faster into the GPS receiver, allowing the receiver to know almost instantly which satellites on which channels it is supposed to listen to. For this purpose, an extended GPS system, which is known as *Assisted GPS* (*A-GPS*), is the norm in modern smartphones and is the reason why your phone can find your location the moment you turn it on, even after an intercontinental flight.

For aviation, GPS now offers another, inexpensive and extremely accurate source of navigation, especially when combined with a moving map technology. With a GPS moving map display, the kind of mistake that doomed *KAL 007* would have been obvious to detect, as the plane's deviation from the designed route would have been clearly visible.

The existing VOR, DME and ILS stations are relatively expensive to maintain, as they require constant monitoring and frequent testing for safety purposes. Hence the current trend is to move more and more towards *satellite-based navigation systems* in aviation.

The unprecedented precision of GPS with WAAS support has made it possible to create *virtual approach procedures*, closely resembling the ones provided by the ILS system. As these do not require any hardware at the designated airports and are therefore totally maintenance-free, they have created safer means for airplanes to land at even small airports in poor visibility. More importantly, in addition to making thousands of airports more available, these new, GPS-based approach procedures have made it possible to decommission many expensive-to-maintain ILS approach systems from less active airports, thus maintaining the same level of service with zero maintenance cost.

The same fate as with low-traffic ILS systems is expected for many of the VOR stations—only a bare-bones backup grid for the standard airways will be maintained in the future, as waypoints can just as well be defined via GPS, with much greater flexibility than by using only VOR radials.

The GPS system has made navigation cheap and easy worldwide, on land, at sea and in the air, and has created major cost savings and safety improvements. Additionally, having accurate location information universally available around the globe has created all kinds of new services and businesses that were impossible just a couple of decades ago.

But it has also injected a massive single point of potential failure in the system: as the GPS signals are received from satellites that orbit at an altitude of over 20,000 kilometers, the received signals are extremely weak and thus vulnerable to any interference on the same frequency band. This was an issue during the Persian Gulf War in 1991, when Iraqi forces used GPS jammers around sensitive military targets, and it is unlikely that GPS could be fully relied upon in any modern event of active warfare: even in our current civilian times, there has been reports of huge deviations being noticed in various parts of the Russian Federation, including near the Kremlin in Moscow, as well as on the shores of the Caspian Sea. Similarly, GPS reception at Newark airport was repetitively disrupted by a passing pick-up truck in 2013, as the driver was using a GPS jammer to hide his whereabouts from his employer. He was eventually caught and fined 32,000 dollars for his efforts.

In the unfortunate reality of constantly competing military forces, a system controlled by the armed forces of a single, potentially hostile country will naturally not be to the liking of everyone. As a result, an alternative system called *GLONASS* was created by the Soviet Union, and it continues to be maintained by Russia. China has its own *BeiDou* satellite system in orbit, originally targeted only to cover mainland China but with global expansion plans. Similarly, India has its own regional system, covering an area around the Indian Ocean from Mozambique to Northwestern Australia and all the way to the Russian border in the North, while Japan is working on their super-accurate, regionally optimized GPS enhancement, *Quasi-Zenith Satellite System* (*QZSS*), expected to be fully operational in 2018.

Most recently, the *Galileo* system by the *European Union* and the *European Space Agency* (*ESA*) went live in 2016, after seventeen years of development worth 11 billion dollars, only to be hit by issues with the super-accurate atomic clocks onboard the satellites. It should be in full use in 2020, ultimately surpassing the precision level offered by the GPS system. Like GPS and GLONASS, Galileo is offering global coverage.

Most modern GPS receivers can synchronize with some functional combination of these parallel systems, hence providing redundancy for the users against a major malfunction or deliberate disconnect in one of them. Yet all of these systems are based on satellites, which are in danger of being hit simultaneously by a major *solar storm*, the worst of which in our recorded history, known as *The Carrington Event*, happened in 1859. There has not been anything comparable during our recent Space Age, and therefore we have no knowledge of how an event on an equal scale would affect not only GPS, but other satellites as well—all we know is that *something* will certainly break, but we have no idea of how widespread the devastation will be.

LORAN was deemed to become obsolete in the aftermath of making GPS available for all, and most European LORAN transmitters were shut down in 2015. Occasionally there has been some renewed interest for an upgraded *Enhanced LORAN (eLORAN)* version, which would function as a backup in case of catastrophic GPS outage.

The promised advantages of eLORAN are based mainly on improvements on the receiver technology, reaching an accuracy of tens of meters. Despite many suggestions around the world, at the time of writing this, the only countries still actively working on eLORAN are Russia and South Korea.

Although the use of moving maps on our smartphones today is amazingly easy from the end users' point of view, the technology behind generating that location information is by far the most mathematically complex use of radio waves ever designed by mankind.

So far.

Finally, the multitude of overlapping systems that are offering basically the same service is a sad reminder of how we are still bitterly divided into nation states, even though we all share the same *pale blue dot* in space. Running each of these services costs millions per day, and GPS alone has cost over 10 billion dollars to build so far. The estimate for the cost of running Galileo for 20 years has gone up from about 9 billion dollars to 25 billion dollars.

Even though the demand for high-precision location information is global and shared by all nations, there is no push to establish a shared system that would be managed by some neutral body like the *United Nations* (*UN*). As long as there is a clear military use for a service, honest collaboration between the artificial tribes of the world appears to be impossible.

In many other areas, though, international collaboration in the utilization of space has been extremely effective: one particular success story is the *Cospas-Sarsat* program, which has over 40 satellites in various orbits, listening to *406* MHz *distress beacons*. These *Emergency Position Indicating Radio Beacons* (*EPIB*) are standard equipment in ships and airplanes, but can also be purchased as portable *Personal Locator Beacon* (*PLB*) units for individual use.

Cospas-Sarsat satellites immediately detect any 406 MHz signal, emanating from anywhere in the world. The transmission contains digitally transmitted information consisting of the originator ID and the GPS-derived location. Most airplanes have EPIB-equipment on board, as a self-contained unit, connected to an internal battery and an impact sensor that activates the beacon automatically after an accident.

As the GPS position in the message might not be up to date, the satellites also perform their own location detection algorithm based on the *Doppler effect*, like the "reverse Sputnik" approach discussed above, and then relay all information to the several tens of automated ground control stations, which transfer the information to regional *Mission Control Centers* (*MCC*).

The system has been operational since 1982, and currently there are more than 550,000 registered EPIB and PAB devices. On average, more than 2,000 persons are rescued annually by the system, in over 700 emergency events around the world.

Cospas-Sarsat is a perfect example of functionality in which the user interface of a device is extremely simple: the triggering happens either automatically through sensors or by a button press. But everything that follows thereafter is very complicated: numerous satellites receive the signal, calculate positions based on complex mathematics and then relay all information to MCCs scattered around the globe.

This is an amazing example of how the harnessing of these invisible waves has made it possible to create a worldwide system that saves lives daily.