NCW 101 NETWORKED OPERATIONS

Pseudolites and Stratospheric Relays

NCW 101 Part 11

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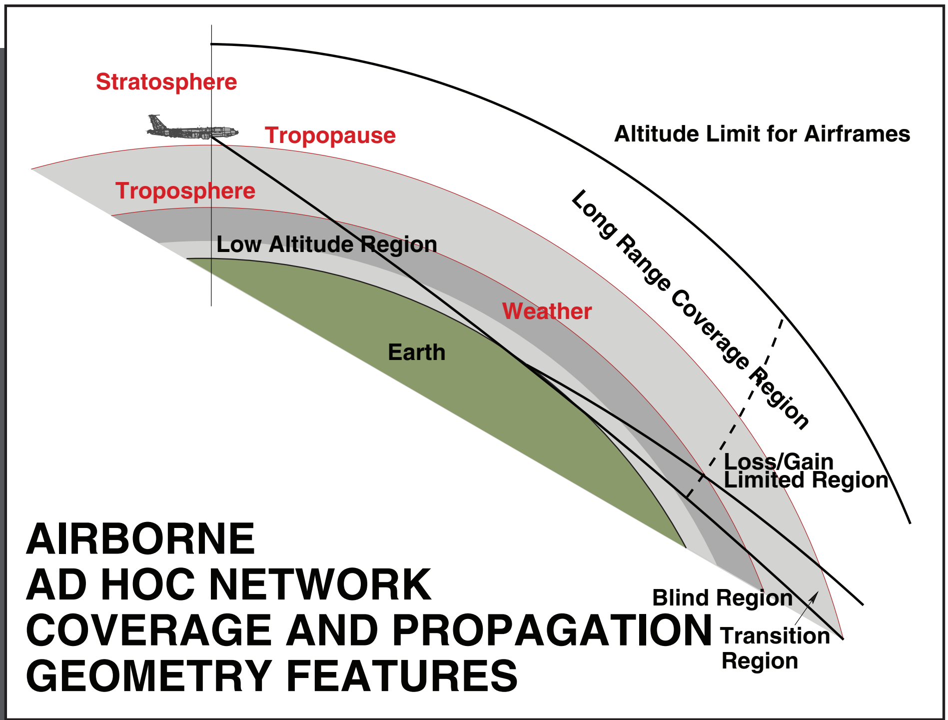
Pseudo-satellites or 'pseudolites' are an emerging substitute for satellite communications (Satcom) that promise similar capabilities, albeit over smaller footprints, but with potentially much lower costs and very high achievable bandwidths.

The central idea underpinning all pseudolite schemes is the use of High Altitude Long Endurance (HALE) Uninhabited Aerial Vehicles (UAV) or dirigibles to carry digital communications relay packages not unlike those carried by satellites. Orbiting at stratospheric altitudes, pseudolites can provide low latency, high persistence and high data rates at the fraction of the cost of a satellite system.



Pseudolites versus Satellites

As noted in previous discussion of satellite communications, the Geosynchronous Earth Orbit (GEO) model dominates contemporary satcom systems, to the extent that significant orbital congestion exists in areas above high population density parts of the world. GEO systems are, however, expensive to lift due to the high orbital altitude, expensive to build due to the harsh radiation environment at that altitude, demanding in antenna sizes and power levels required with increasing radio link capacity, and unavoidably penalised by propagation latency due to the high orbital altitude.

While satcom systems at lower orbits suffer much less from the latency and link capacity problems, the need to launch multiple satellites to achieve persistent coverage of a single geographical area drives up cost and complexity. While a Low Earth Orbit (LEO) system outperforms a GEO system on latency and radio link capacity per dollar invested, having to launch dozens of satellites and effect global coverage has seen such systems go mostly bankrupt.

The three technical issues which favour the pseudolite model are latency, path loss (or capacity), and persistence.

Latency is the time elapsed between a signal departing a transmit antenna on the earth's surface, propagating up to the satellite or pseudolite, passing through the onboard communications hardware, departing the transmit antenna, propagating back down to earth, and finally impinging upon the earth-bound receive antenna. For a GEO satellite, latency can be as great as 250 milliseconds (or more), for an MEO satellite of the order of 50-100 milliseconds and for an LEO satellite of the order of 10 milliseconds. Such delays are irrelevant if the signal is broadcast TV or radio, but they can cause real difficulty with digital data, especially where more complex protocols are used.

Path loss is an equally painful problem with satellites. Disregarding the effects of the lower atmosphere, the reality is that the power level into the receiver declines with the inverse square of distance from the transmitter. The further, the bigger the antennas and the more power has to be emitted to achieve an intended bit rate over the channel. Bigger antennas and more power translate directly into costs – at the satellite end and at the ground station end of the link – if we want serious bandwidth. Therefore low cost and high bit rates are mutually exclusive in the satellite game.

Sending microwaves through the lower atmosphere however causes further pain to the satellite system designer, since the lowest layer of the atmosphere, the troposphere, is laden with free water vapour, water droplets as cloud and rain, and gaseous oxygen. Operating in the less congested centimetric bands, this tropospheric "soup" will soak up the signal very rapidly. Rain and dense clouds are particularly problematic.

If the satellite is directly overhead, the distance through this soup is minimal but if the satellite's position in the sky is moved away from the zenith, things get increasingly worse. This has been one of the big selling points of LEO satellites compared to GEO satellites, in that within the heavily populated temperate zones of the earth your GEO satellite dish is at a disadvantage, operating at a very shallow elevation angle.

When bouncing microwave signals off a payload on a stratospheric platform, HALE UAV or dirigible, things change dramatically. The distance between the antenna shrinks from thousands or tens of thousands of kilometers to mere tens of kilometres, with elevation angles typically above 20 degrees. As a result, the distance and thus latency drop by a factor of between 25 and 1000 compared to LEO and GEO satellites respectively.

No less importantly, path length loss drops dramatically because of the inverse square law relationship, and long paths through the tropospheric soup are minimised. As a result, a user can achieve a very high bit rate with a fraction of the transmitted power and antenna size required to achieve the same when bouncing off a satellite.

The physics of microwave propagation and Shannon's law of channel capacity give the airborne system an unchallenged advantage over the satellite.

The issue of on-station persistence also needs to be considered. While a GEO satellite has persistence of years, until wearout or failure disables the vehicle or payload, such systems suffer unavoidable limitations in cost/bandwidth and latency. MEO and LEO systems are much better in both of these respects but provide only transient coverage at any given geographical point.

The essential tradeoff is to either use a fraction of the capacity of a larger global LEO/MEO satcom system for local coverage, or rotate a small number of airborne pseudolites through a local airborne orbit to achieve the same coverage and bandwidth effect. The economics in this play will always favour the airborne system.

Defining a practical Pseudolite system

Airborne vehicles have other, more pragmatic advantages over satellites. They are much cheaper to build and operate, in comparison with satellite manufacture (largely built by hand), and the prohibitive costs of putting them into orbit.

Airborne communications payloads can also be designed and built to a much cheaper commercial avionic standard, since they can be repaired easily on the ground, a choice not available to a satellite operator. The atmosphere shields much of the radiation that can damage satellites and degrade their semiconductor electronics over time, thereby contributing to a much greater operational life for the electronics.

In practical terms, an airborne package can be maintained in service indefinitely by ongoing repairs, preventive maintenance, and can be upgraded and modified at any time. Those who may doubt this should consider that the B-52s, which may be in service up to 2040, were built in the early 1960s. Many civil and military aircraft in service today were built in the fifties and sixties.

Should a satellite be lost due to failure, getting a replacement into orbit can take years. With aircraft, a spare may be airborne in minutes if it is fuelled and ready.

What are the limitations of aircraft compared to satellites? First and foremost, aircraft are quite limited in footprint and setting a 20-degree ground station elevation angle as a limit, an aircraft can reach out to a distance of about three times their operating altitude. To cover a radius of 100 km the aircraft needs to be at about 100,000 ft altitude. At a 50-60 km radius we get an altitude of about 50,000-60,000 ft, which is the domain in which the proposed commercial HALO (bought out by Raytheon and not progressing) and in which military DARPA ACN pseudolite systems were intended to operate.

The second limitation of aircraft is endurance. Unlike a satellite which hangs in orbit, an aircraft needs to be fed on energy to remain aloft. Excluding the solar powered NASA ERAST project, this means hundreds or thousands of litres of kerosene to remain airborne for a decent number of hours.

Addressing the requirements of stratospheric operating altitude and long endurance, such as 8, 12, 16, 24 hours or longer, we end up with a aircraft not unlike the U-2 which is the progenitor of the species - very large wings, and very light structure. Such aircraft are finicky to fly and hard to handle on the ground.

As a result, an aircraft capable of replacing a satellite will be limited in terms of the severity of weather it can handle on takeoff or landing, and if 45 knot gusting winds hit its home base airfield, it will have to go elsewhere to refuel.

Providing an aircraft can be built which has the aerodynamic efficiency to sustain flight for 8-12 hours in the stratosphere, with a decently sized communications payload, then the advantages of an airborne system over a satellite can be realised.

Dirigibles or Light Than Air (LTA) platforms have been proposed as an alternative to conventional aircraft or UAVs for these applications. A dirigible, be it rigid, semi-rigid or soft-skinned, is a modern offspring of the historical Zeppelin.

The tremendous advantage offered by a dirigible is that it does not need to burn fuel to remain aloft, as its lift is derived from the buoyancy of the gasbag. The difficulty presented by dirigibles is that the volume of a gasbag required to lift even a modestly sized payload to the stratosphere is very large, driving up unit costs compared to a UAV platform. The result is a large and expensive vehicle, with a large infrared, visual and often radar signature.

An unresolved issue is that of powering a dirigible system's communications package. While kerosene may not be required to sustain flight when orbiting on station, with a multi-kiloWatt communications package it will be required to provide electricity for 24/7 operation of the payload.

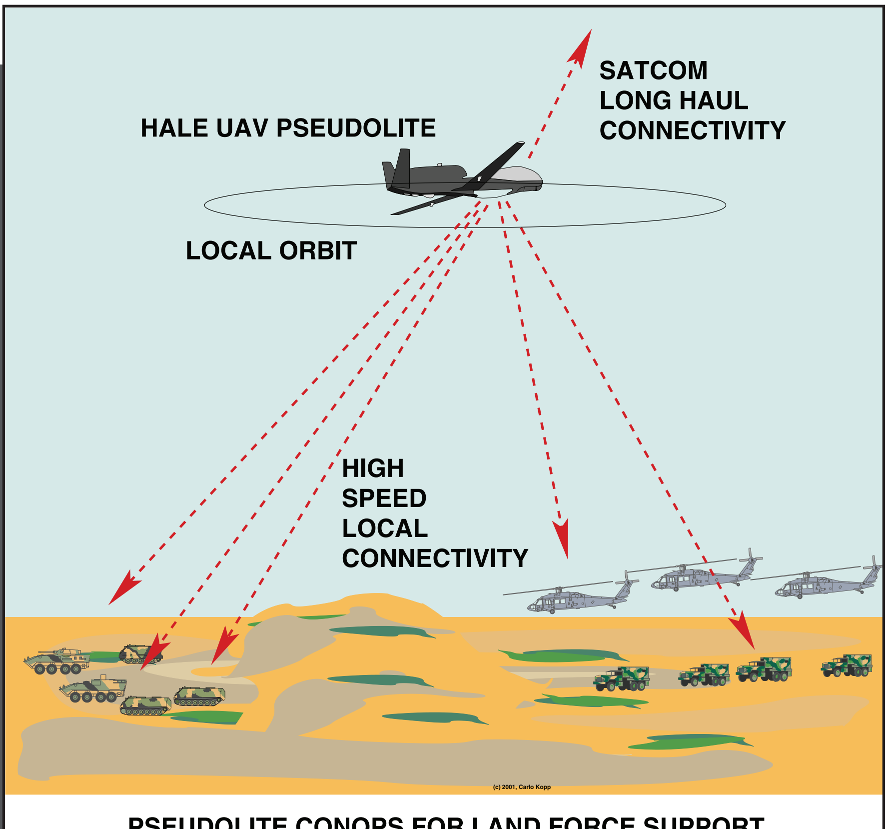
Solar power has been proposed as the solution to the problem of keeping both UAVs and dirigibles aloft for days on end, and powering their thirsty payloads. The idea is to clad the upper skin of the dirigible or UAV with lightweight solar cells to generate electricity, and store that electricity using lightweight batteries or fuel cell based hardware, to permit operation through nighttime darkness. This is a conceptually very elegant idea, insofar as a pseudolite powered in this fashion could remain aloft for days, weeks or months, needing to land only for scheduled maintenance and unscheduled repairs.

Unfortunately, the technology of this period cannot provide the required electrical power within reasonable weight and cost constraints, if at all. There is no solar cell technology at present that is efficient enough, light enough and cheap enough to be viable. While small ISR payloads with passive sensors are feasible, a multi-kiloWatt digital communications package is not.

The pragmatic reality of today's technology is a winged UAV powered by a JP-8 fuelled turbine is limited in airborne endurance by the internal fuel payload.

Robotic aerial refuelling will be a solution to extending endurance of such systems in the forseeable future. Both the US Air Force and US Navy have been investing in research projects to enable UAVs to refuel in flight, and as this technology matures, aerial refuelling will become the technology of choice in extending UAV endurance.

The issue of aerial refuelling of UAVs also raises the comparison of 'smart tankers' equipped as communications relays versus UAV based pseudolites. Operating at much lower altitudes than HALE UAVs, smart tankers have inherently lower coverage footprints than such UAVs. On the



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other hand, they have abundant electrical power and unused capacity for relatively large payloads and antennas. Where a good density of smart tankers can be achieved in a battlespace, and all else being equal, the 'smart tanker' is the better play economically and in terms of operational resources to provide the capability.

Where tankers are in short supply, then a dedicated UAV payload, or a supplementary UAV payload becomes very attractive.

To date most of the debate on pseudolites has been focused on providing capabilities for land and naval forces, as a substitute for overburdened satellite resources.

Pseudolites however open up other possibilities. One of these is the provision of medium to long haul temporary high data rate backbone connections between geographical areas of interest.

Considering a scenario such as the occupation of East Timor or the Tsunami relief effort, in Australia's immediate region, the conventional pseudolite model when applied provides what amounts to a high speed data and voice switch, and local relay capability, in the immediate theatre and area of operations. If the HALE UAV employed for this purpose has a high speed X-band or Ku-band satellite link capability, satellite capacity permitting, it can provide long haul connectivity to headquarters elements in Australia. Where the demand for long-haul capacity is modest or low, this is a viable model. The pseudolite provides fast high capacity local connectivity, and limited long haul connectivity.

Where the demand for long-haul connectivity is greater this model is problematic, as the pseudolite does not contribute long haul capacity, it merely acts as a user level interface to the satellite capability.

If a pseudolite is, however, equipped with a suitable communications relay package, allowing traffic to hop from pseudolite to pseudolite, then a chain of pseudolite orbits spaced at suitable intervals allows traffic to flow along the chain, providing a substitute long haul capability replacing satellites.

A HALE UAV used in this regime will require a high-power phased-array antenna package, comparable to current fighter phased array (AESA) radar designs. Data rates of hundreds of Megabits per second at distances of the order of 400 – 500 nautical miles between orbits are, however, achievable without unusual difficulty with this technology.

An example scenario could be an operation taking place 1,400 nautical miles from Darwin. One UAV orbit is positioned around 200 nautical miles from Darwin providing connectivity to a ground station, the next orbit is at 600 nautical miles, the next at 1,000 nautical miles and the final orbit at 1,400 nautical miles, supporting assets in the area of operations. Four UAV orbits, supportable with 6 to 8 UAVs, provides the kind of capability only delivered by a top end satellite capability, at a fraction of the cost. Once the operational imperative is over, the UAVs are redeployed.

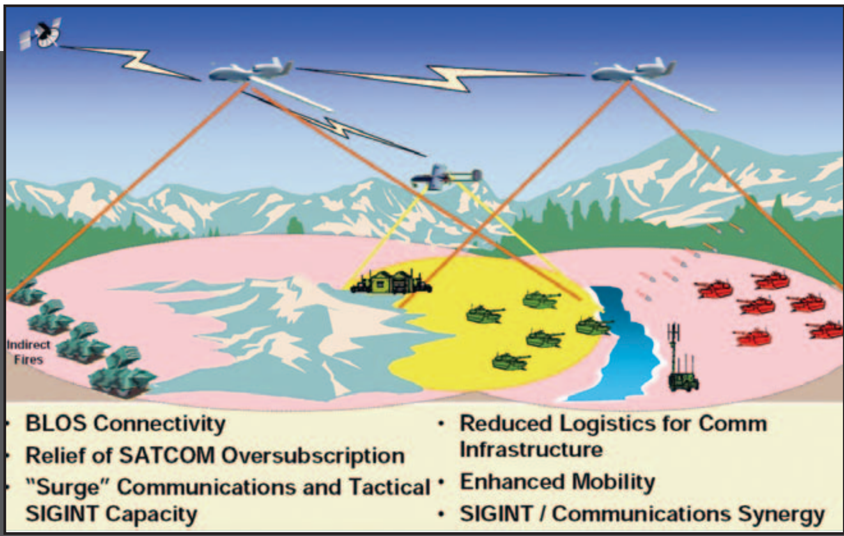
From a survivability perspective, HALE UAVs are easier to kill than satellites but harder to kill than conventional aircraft due to their station altitude, requiring a Flanker or F-15 class fighter to fly an afterburning zoom climb attack to loft a missile shot, or requiring a genuine counter-ISR missile like an R-37 or R-172. In many contingencies, such as long-range backbone relays, most UAV orbits would be well out of the range of hostile fighters, and those within range would need to be defended by fighter Combat Air Patrols.

Airframes for Pseudolite applications

The size, payload, cooling and power demands of a pseudolite system will be driven by the weight and power demands of the communications package, and the range and on station persistence demands of the end user.

The US Air Force and DARPA initiated research on a pseudolite package for the RQ-4A Global Hawk during the mid to late 1990s, initially labelled the Airborne Communications Node. This program has since evolved into the Adaptive Joint C4ISR Node (AJCN), which ran between 2003 and 2005, to validate a Joint Tactical Radio Systems (JTRS) based payload using a Shorts C-23 Sherpa as a test aircraft platform, aiming to test payloads on Hunter UAVs and NKC-135 test bed aircraft. Further tests were planned for 2006-2007 but little has been published, and given current US budgetary pressures it is unclear how robust funding is longer term.

What is clear is that pseudolites are the answer for the ADF's problem of providing regional high-speed connectivity to support military networking. What is less clear is whether this technology and its enormous future impact is understood in Canberra, given its absence in any published material.



above: The DARPA AJCN proposal.