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THE UTILITY OF A TACTICAL AIRBORNE COMMUNICATIONS SUBSYSTEM IN SUPPORT OF FUTURE LAND WARFARE

by

Michael Ryan

and

Michael Frater

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About the Authors

Dr Michael Ryan is a Senior Lecturer in the School of Electrical Engineering at the Australian Defence Force Academy (ADFA). He has twenty years experience in battlefield communications and information systems. He is a graduate of the Royal Military College, Duntroon; the Telecommunications Engineering Management Course (UK); and of the Australian Army Command and Staff College. Throughout his military career, he has held a range of regimental and staff appointments. He holds Bachelor, Masters and Doctor of Philosophy degrees in electrical engineering. Dr Ryan is an internationally recognised expert on battlefield command systems and has studied battlefield communications systems in Australia, United States, and Europe. He is the Editor-in-Chief of the international journal, *Journal of Battlefield Technology*, and is the author of a number of articles and a book on battlefield command systems, and is the co-author of books on tactical communications architectures and electronic warfare. In his capacity as a part-time Army officer, Lieutenant Colonel Ryan is a Senior Research Fellow at the Land Warfare Studies Centre.

Dr Michael Frater is an Associate Professor in the School of Electrical Engineering at ADFA. He has more than ten years experience in the development of communications systems and services, including video conferencing and video and image surveillance. He has led ADFA involvement in a number of collaborative projects, investigating tactical image and video communications. He has been actively involved in the development of international standards for audiovisual communications and currently chairs the group within the Moving Picture Expert Group (MPEG) concerned with wireless and mobile applications of this technology. He holds a Bachelors degree in Electrical Engineering and a Doctor of Philosophy in Systems Engineering. He is the author of a number of articles on communications systems and communications services, and is the co-author of books on tactical communications architectures and electronic warfare. Captain Frater is also a part-time Army officer in the Royal Australian Signals Corps, currently serving with 8 Signal Regiment.

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The Director
Land Warfare Studies Centre
Ian Campbell Road
DUNTROON ACT 2600
Australia

Telephone: (02) 6265 9548
Facsimile: (02) 6265 9888
Email: dir.lwsc@defence.gov.au

ABBREVIATIONS AND ACRONYMS

ACN	airborne communications node
ADA	air defence artillery
ADF	Australian Defence Force
AO	area of operations
ATM	asynchronous transfer mode
AWACS	Airborne Warning and Control System
C2	command and control
C3	command, control, and communications
CCE	communications control element
CCM	communications control module
CDL	common data link
CMC	communications manager/controller
CNR	combat net radio
COMSEC	communications security
EPLRS	Enhanced Position Locating and Reporting System
EW	electronic warfare
FAA	Federal Aviation Administration
GBS	Global Broadcast System
GPS	Global Positioning System
HALO system	High-altitude Long-operation system
HF	high frequency
JTF	joint task force
LOS	line-of-sight
LPD	low probability of detection
LPI	low probability of interception
LRE	launch and recovery element
MSE	Mobile Subscriber Equipment
NBC	nuclear, biological and chemical
OTAR	over-the-air rekey
PCS	personal communications systems
SAR	synthetic aperture radar
SHF	super-high frequency

SINCGARS	Single-channel Ground and Airborne Radio System
TACSAT	tactical satellite
UAV	uninhabited aerial vehicle
UHF	ultra-high frequency
VHF	very high frequency
WIN	Warfighter Information Network

ABSTRACT

In future land warfare, support for command and control requires the development of a single logical network that provides connectivity between any two points in the battlespace, and between any point in the battlespace and any point in the strategic communications system. This *Tactical Communications System* must be an organic asset that provides at least the minimum essential voice and data communications requirements to support situational awareness within the deployed force and to allow for the transfer of command-and-control information. The Tactical Communications System can be seen as comprising five subsystems: *Combat Radio Subsystem*, *Tactical Data Distribution Subsystem*, *Tactical Trunk Subsystem*, *Tactical Airborne Subsystem* and *Local Subsystem*.

The airborne communications platform of a Tactical Airborne Subsystem provides additional capacity and extends ranges of the Combat Radio and Tactical Trunk Subsystems when required by the operational scenario. Traditionally, the solutions to the provision of high-capacity, long-range communications have relied on the use of satellite-based services. However, subspace platforms (airborne rather than space-borne) offer a viable alternative, with the potential to deliver a broader range of services more cost-effectively.

In addition, the Tactical Airborne Subsystem allows for command and control on the move across an area of operations with a radius of between 200 and 500 km. The deployment of an airborne platform offers additional opportunities in the provision of other communications services, such as theatre broadcast and personal communications systems. Despite the need to resolve a number of technical challenges, there are a number of potential subspace platforms that will be able to meet the requirements of a Tactical Airborne Subsystem.

This paper examines the utility of a Tactical Airborne Subsystem in support of future land warfare. Advantages of an airborne communications platform are discussed, and payload requirements are analysed. Some limitations are examined before an upper-level architecture is presented. The paper also discusses potential platform types (piloted and uninhabited aircraft, and aerostats) and outlines relative costs.

THE UTILITY OF A TACTICAL AIRBORNE COMMUNICATIONS SUBSYSTEM IN SUPPORT OF FUTURE LAND WARFARE

INTRODUCTION

Support for command and control in future land warfare requires a Tactical Communications System that is a single logical network providing connectivity between any two points in the battlespace. The Tactical Communications System is an organic asset that provides at least the minimum essential voice and data communications requirements to support situational awareness within the deployed force and to allow for the transfer of command-and-control information. The Tactical Communications System interfaces with the Strategic Communications System to provide seamless connectivity between any two points in the battlespace, and between any point in the battlespace and any point in the Strategic Communications System. The rationale behind the development of the architecture for the Tactical Communications System is presented in Land Warfare Studies Centre Working Paper no. 109.[1]

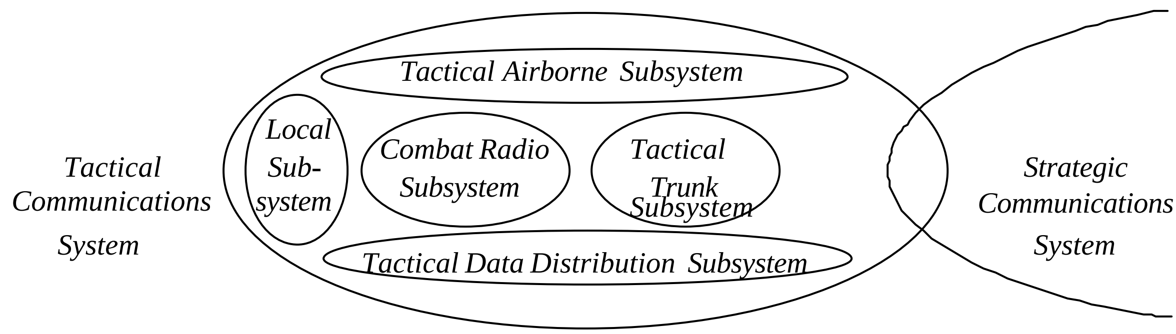

Figure 1: Components of the Tactical Communications System and Strategic Communications System

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1 M. J. Ryan and M. R. Frater, *A Tactical Communications System for Future Land Warfare*, Working Paper no. 109, Land Warfare Studies Centre, Duntroon, ACT, March 2000.

As illustrated in Figure 1, the Tactical Communications System comprises five subsystems:

- *Combat Radio Subsystem*, providing the mobile infrastructure to support voice and data communications to support the command and control of combat troops;
- *Tactical Data Distribution Subsystem*, providing high-capacity data communications to support the situational awareness required for the command and control of combat troops;
- *Tactical Trunk Subsystem*, providing the transportable infrastructure to support communications between command elements and other large-volume users;
- *Tactical Airborne Subsystem*, providing range extension and additional capacity, when the tactical situation allows; and
- *Local Subsystem*, simplifying the user interface to the other communications subsystems and to overlaid communications systems.

This paper examines the utility of a Tactical Airborne Subsystem in support of future land warfare. Advantages of an airborne communications platform are discussed and payload requirements are analysed. Some limitations are examined before an upper-level architecture is presented. The paper also discusses potential platform types (piloted and uninhabited aircraft, and aerostats) and outlines relative costs.

ADVANTAGES OF AN AIRBORNE COMMUNICATIONS PLATFORM

An airborne communications platform can be used to provide additional capacity and to extend ranges of the Combat Radio and Tactical Trunk Subsystems when dictated by the operational scenario. Traditionally, solutions to the provision of high-capacity, long-range communications have relied on the use of satellite-based services. However, subspace platforms (airborne, rather than space-borne) offer a viable alternative, with the potential to deliver a broader range of services more cost-effectively.

Before addressing the issues in detail, it is worth briefly considering the number of significant advantages to the operation of an airborne communications platform, which can offer a broad array of services with low operating costs compared with satellite-based systems:

- Airborne platforms do not require a launch vehicle; they can move under their own power throughout the world or remain stationary.
- Each platform can be retrieved and relaunched, allowing the communications payload to be brought down to earth and routinely serviced for optimal performance.
- Airborne platforms can be steadily enhanced with emergent technologies (unlike satellite communications payloads, which remain fixed in the deployment configuration).
- Once a platform is in position, it can immediately begin delivering service to its service area without the need to deploy a global infrastructure or a constellation of platforms to operate. Coverage can therefore be provided more rapidly to areas of operation without having to have significant satellite assets covering the area of potential tasks in defence of Australia and regional interests.
- The aircraft is 20 to 2000 times closer to the user than a satellite, with ten times the available electrical power. The relatively low cost of the platform and gateway stations make it the cheapest wireless infrastructure per subscriber over large areas.
- The subspace altitudes provide short paths through the atmosphere, and higher antenna elevation angles provide most subscribers with unobstructed line-of-sight to the platform.

- Airborne platforms have much lower transmission delays—tens of microseconds compared to tens to hundreds of milliseconds for satellite.
- With small antennas and low power requirements, an airborne communications platform can support a wide variety of fixed and portable user terminals to meet almost any service need.
- Unlike satellite systems, which are 'all or nothing' multibillion-dollar investments, airborne platforms can be procured one at a time as strategic guidance and budgets allow.
- Much lower capital investments are required—tens to hundreds of millions of dollars compared to several billion.

These advantages offer significant tactical benefits. However, it should be noted that, as with any practical system, there are some operational limitations, which are discussed in a later section.

PAYLOAD REQUIREMENTS

The Tactical Airborne Subsystem provides an airborne platform that carries robust communications packages to support command and control across wide areas. High-gain antennas coupled with the ability to loiter at high altitudes for extended periods will enable tactical users equipped with lightweight omnidirectional antennas and low-power radios to establish long-range communications from mobile platforms. This capability will provide a significant improvement in communications ranges and will enhance the ability for commanders to command and control on the move. The Tactical Airborne Subsystem is required to provide the following:[2]

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[2] M. J. Ryan and M. R. Frater, *A Tactical Communications System for Future Land Warfare*, LWSC Working Paper no. 109, Land Warfare Studies Centre, Duntroon, ACT, March 2000.

- range extension of Combat Radio, Tactical Trunk and Tactical Data Distribution Subsystems; and
- additional communications services, including:
  - surrogate satellite communications, and
  - coverage extension of Overlaid Communications Systems, such as Personal Communications Systems and the Theatre Broadcast System.

Range Extension

The major requirement for a Tactical Airborne Subsystem is to extend the range (mainly through retransmission) of the other subsystems of the Tactical Communications System:

- **Combat Radio Subsystem.** The Tactical Airborne Subsystem must be capable of performing retransmission for nets within the Combat Radio Subsystem.
- **Tactical Trunk Subsystem.** The airborne radio relay will connect widely dispersed trunk nodes on the battlefield.
- **Tactical Data Distribution Subsystem.** This subsystem is used to broadcast situational awareness data. The relay can be used to link enclaves that are beyond line of sight or to act as a relay for terminals in order to facilitate their dispersal.

As illustrated in Figure 2, the range extension offered by an airborne communications platform is very significant. In their normal terrestrial modes, combat net radio (CNR) and radio relay are generally terrain-limited, not power-limited. For example, ground ranges of CNR are limited to 5–15 km, depending on how high the signaller can elevate the antenna. An airborne communications platform extends those ranges to up to 500 km — a dramatic improvement. A single airborne platform could provide coverage of a single area of operation in the north of Australia; alternatively such a platform could provide coverage of both East and West Timor as well as littoral regions. As an extreme example, a single platform flying over the Timor Sea could relay high-frequency (HF) and very high frequency (VHF) communications between East Timor and Darwin as well as provide HF/VHF communications for all ships and aircraft in between.[3] This increase in communications area provides a significant improvement to a commander's ability to command and control. A commander in Dili could have, should he have so desired, established a net on which he could communicate with any subordinate commander or significant platform, provided that those assets can 'see' the airborne platform — whether they were in barracks in Darwin, conducting pre-deployment training in the Northern Territory, afloat deploying to East Timor, securing the airfield at Dili or deploying to the West Timor border. Existing systems do not allow the commander to talk to subordinates in all phases of deployment; in fact, direct communications are currently impossible for extended periods during such operations. An airborne communications platform would provide commanders with command and control on the move over a large operational area.

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[3] Due to the nature of the terrain in East Timor, the airborne platform would need to be stationed closer to Dili than Darwin due to the terrain screening of the central highlands; see later section on limitations.

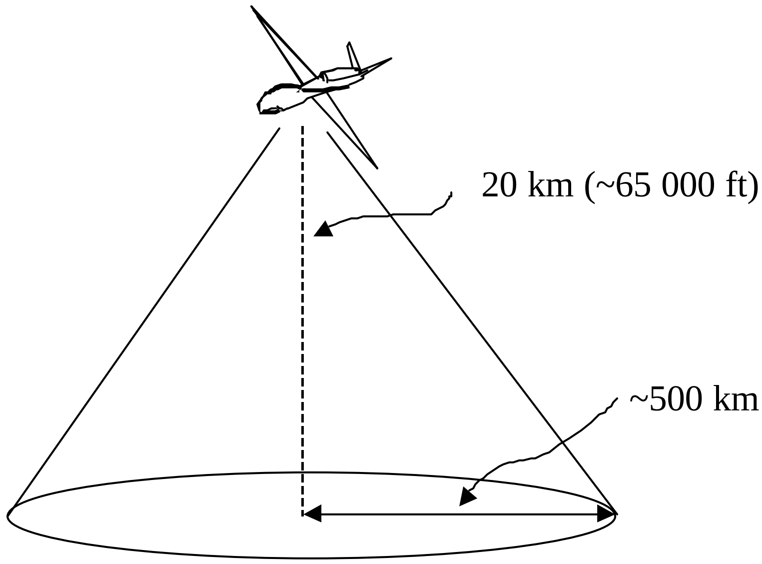

Figure 2: Footprint of Airborne Communications Platform

For example, had an airborne communications platform been available during the Gulf War, true communications-on-the-move could have been provided to support a fast-moving, wide-ranging envelopment, at a time when terrestrial networks were stretched to breaking point.[4]

Cross-linking. Further extension in coverage can be provided by cross-linking between platforms, as illustrated in Figure 3. However, it should be noted that cross-linking requires antennas with fairly high gains that have to be accurately pointed to another airborne platform. Therefore cross-linking represents some engineering challenges for most platforms except those that can be maintained in a geostationary position, although modern phased-array antennas go some considerable way to solving this problem. The inclusion of a cross-linking capability will reduce the communications payloads on board the platform.

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4 M. Mcallister and S. Zabradac, 'High-altitude-endurance Unmanned Aerial Vehicles Pick Up Communications Node', *Army Communicator*, Spring 1996.

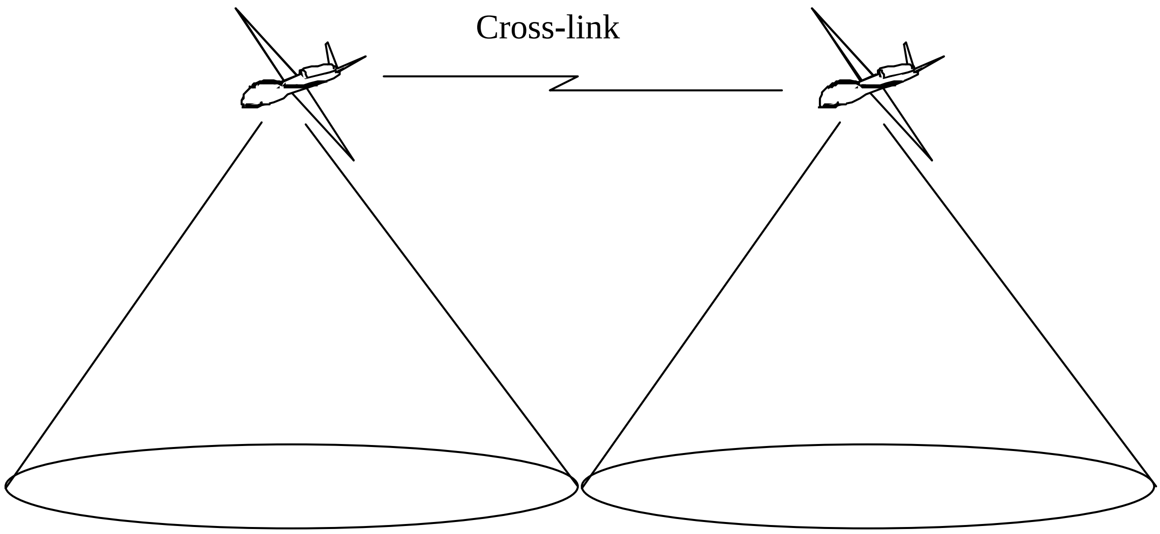

Figure 3: Increased Coverage by Cross-linking between Airborne Platforms

Additional Communications Services

Once the requirement for a Tactical Airborne Subsystem has been accepted on the basis of range extension for the other subsystems in the Tactical Communications System, a number of additional communications services can be provided from the airborne platform.

Intra-battlespace Communications. As alluded to in the previous section, an airborne platform presents the opportunity to provide true joint and combined communications in a simple manner. Figure 4 illustrates how the airborne platform can relay communications and establish a net between joint assets as well as provide reach-back communications by satellites in either low- or geostationary-earth orbit.

Surrogate satellite Communications. It may also be possible to mount a surrogate satellite transponder on board the airborne platform. In-service satellite ground terminals could be used to communicate to the surrogate transponder rather than to a satellite. Since the airborne platform is much closer, lower powers (higher data-rates) are possible throughout the area of operations (AO), without having to be within the satellite footprint.

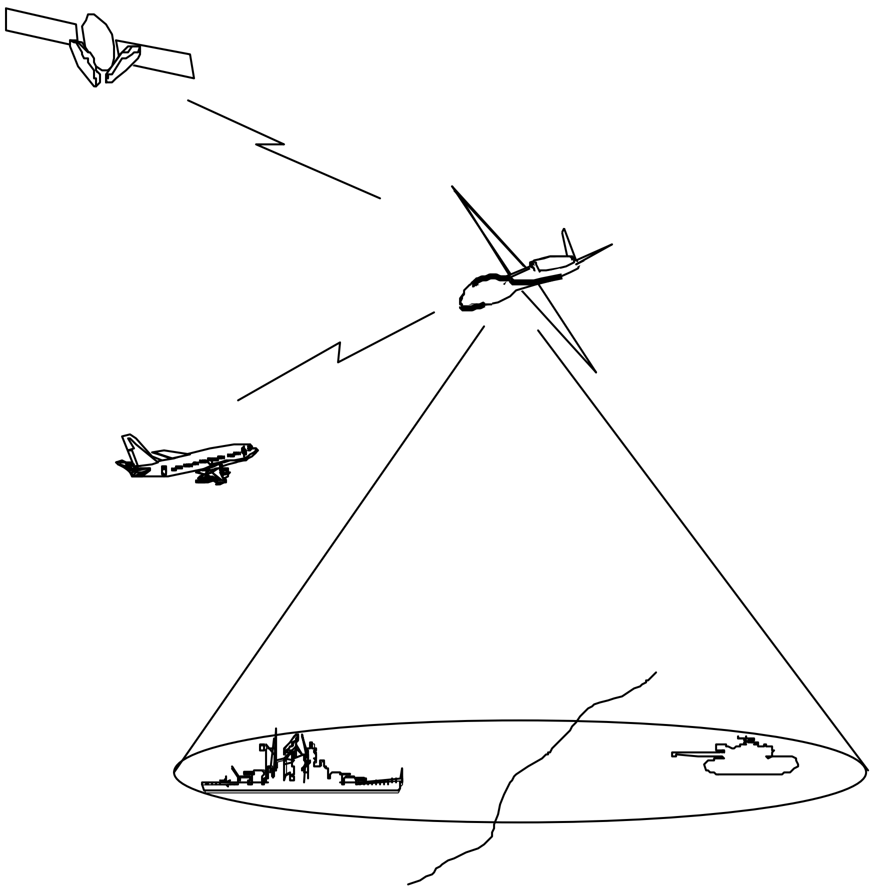

Figure 4: Improved Battlespace Communications

Link-16 Repeater. Provision of Link-16 communications to terrestrial terminals generally poses an intractable problem due to the inability of the terminals to 'see' each other. An airborne Link-16 repeater could extend coverage to terrestrial terminals across the AO, greatly facilitating sensor-to-shooter communications.

Personal Communications Systems (PCS) Access. It may be possible to mount a cellular PCS base-station on the airborne platform and provide digital mobile telephony coverage within the footprint. However, commercial PCS base-stations tend to be large and heavy, although there are some moves within commercial industry to reduce size and weight since there a number of programs in the US and Europe that are examining the possibility of airborne PCS base-stations. The large power requirements of a base-station provide an additional problem.

However, recent studies[5] have shown that a scaled-down base-station that accommodates sixty simultaneous calls can be included as part the US ACN concept (discussed in more detail in Annex B). Even if a base-station is not included in the platform payload, the airborne platform has the potential to provide a reach-back capability with digital cellular phones to support connection back to a base-station on the ground.

Theatre Broadcast. The airborne platform offers two opportunities with regard to theatre broadcast:

- **Broadcast Relay.** One of the difficulties in getting satellite theatre-broadcast to tactical units is the difficulty that combat troops have in deploying reasonably sized satellite antennas. Broadcast relay would take the satellite broadcast on the airborne platform and re-broadcast it into the footprint in the VHF and ultra-high frequency (UHF) bands. Broadcast communications can then be provided to tactical users who can receive broadcasts with small omnidirectional antennas and low-powered receivers.
- **In-theatre Broadcast.** It is doubtful whether the brigade commander would allow theatre broadcast into the brigade area without modification by brigade staff; the most useful product for brigade units is a broadcast of the brigade/divisional view, rather than a strategic one. In that case, the airborne platform allows the brigade commander to take the satellite broadcast at brigade headquarters, modify and add information, and then provide an in-theatre VHF/UHF broadcast through the airborne platform. Again, any mobile units in the footprint can receive high-capacity broadcast into small, omnidirectional (whip) antennas with low-powered receivers.

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5 TRW Space and Electronics Group, *UAV Communications Payload Study*, US DoD Contract No. F04606-95-D-0069/0009.

Videoconferencing. Should commanders decide that videoconferencing is required, terrestrial solutions are difficult to arrange. However, an airborne platform provides an ideal vehicle for the delivery of videoconferencing facilities into the footprint.

Special-forces Communications. High-capacity, long-range communications are normally difficult for special forces, who are forced to operate using HF. An airborne communications-platform can extend high-capacity communications to special-forces patrols, which can be equipped with small, low-powered receivers with small antennas that do not require to be pointed accurately.

Potential Noncommunications Uses

In addition to communications, the Tactical Airborne Subsystem may also potentially be used for the following:

- **Electronic Warfare.** Just as the airborne platform provides an ideal communications base, it also provides an excellent platform for electronic warfare (EW). Ground-based intercept is invariably terrain-limited, and many more ground assets would be required to have the same coverage as an airborne EW platform.

- **Remote Sensing.** The airborne platform could also provide broad area surveillance of the AO in a range of frequencies, through its ability to carry a range of optical, infra-red, multispectral and synthetic aperture radar (SAR) sensors.

It is not likely, however, that such additional uses could be incorporated on a communications platform without suffering some loss in the platform’s communication ability due to the incorporation of extra equipment, antennas and so on. Sensors also come with considerable additional space and weight requirements as stabilisation systems are often several times heavier than the sensors themselves. Additionally, the operation of a multi-role platform may be difficult to coordinate if the other tasks demanded an operational profile at odds with its communications tasks. For those reasons, it is most likely that additional tasks such as EW and remote sensing would be conducted from separate dedicated platforms, although the same type of platform could be utilised in each role.

Platform Control

The airborne communications platform must be controlled during its operational period. Options include UHF satellite, VHF/UHF line-of-sight and HF.

UHF Satellite. Satellite command links are perhaps the best option as the control station can be anywhere within the satellite footprint. UHF SATCOM coverage can be provided by LEASAT 5, a UHF satellite currently leased by the Australian Defence Force (ADF) to support Navy operations.[6] Increased UHF access will become available when the Optus C1 satellite is operational. One of the advantages of satellite-based command links is that the control station can remain in the strategic environment and that the platform does not necessarily have to be forward-deployed. For the Global Hawk UAV, for example, satellite-based command means that the control station and aircraft base can remain in Australia and reach operating areas that are up to 5600 km (8 hours transit time) away. This operating range adequately covers those areas required for tasks in defence of regional interests or in defence against attacks on Australia.

Direct Line-of-sight (LOS). Direct LOS control would require that the ground control station is always in line of sight of the airborne platform, thereby limiting the range of the airborne platform. As noted in a later section, at the highest operating

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6 G. Hale, *ADF Employment of the Global Hawk Uninhabited Aerial Vehicle (UAV)*, Air Power Studies Centre, Paper no. 76, Royal Australian Air Force, Fairbairn, ACT, July 1999.

points of 20 km, this range is often limited to 200 km for antennas with a 5° take-off angle. The requirement for LOS would also invariably imply that the control station and the platform are deployed forward into the area of operations, increasing system vulnerability and support requirements.

HF. Communications in this frequency band have limited bandwidth but provide longer ranges than both satellite and line-of-sight command links. It is therefore a useful backup system provided that there is sufficient space on the platform.

Example Payload

As an example of an airborne platform, the US ACN is based on the Global Hawk UAV and proposes the following services:[7]

- range extension for ten to twenty combat-radio channels;
- range extension for one to three Enhanced Position Locating and Reporting System (EPLRS) channels;
- range extension for one Link-11 channel;
- tactical wideband relay for two or four channels for the mobile subscriber equipment (trunk subsystem);
- ten to twenty channels for surrogate tactical satellite;
- tactical broadcast capabilities for up to 64 kbps to 1.554 Mbps;
- internet services for up to 600 users; and
- cellular or personal communications system telephony for up to 200 calls.

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[7] R. K. Ackerman, ‘Defense Department Researchers Aim for Sky-based Switchboards’, *Signal*, April 1999.

SOME LIMITATIONS

Despite its major advantages, the use of an airborne platform does have a number of operational limitations, as discussed in the following sections:

- terrain effects on propagation,
- effects of weather on propagation,
- tactical vulnerability, and
- technical challenges.

Terrain Effects on Propagation

Terrain Screening. The footprint coverage of Figure 2 assumes that the earth's surface is not disturbed by terrain. If ground terminals are located on high ground, communications ranges can be extended beyond 500 km. However, on the other hand, the coverage of the airborne platform is limited by the terrain near the ground terminal. The range of 500 km can therefore vary markedly with the type of terrain.

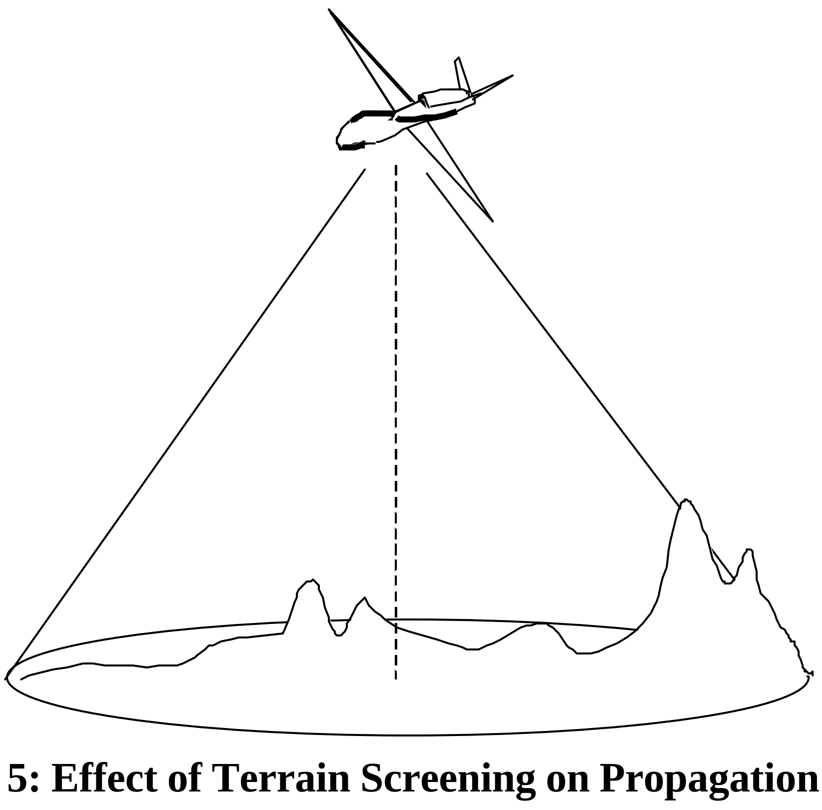

Figure 5: Effect of Terrain Screening on Propagation Range

Antenna Elevation Angle. Even if terrain screening is not as marked as that shown in Figure 5, at higher frequencies the required antenna elevation angle can limit the range of communication to the airborne platform. In particular, super-high frequency (SHF) antennas have a radiation pattern that requires clearance above the earth's surface, which reduces ranges for certain airborne applications such as when it provides a surrogate satellite transponder. Figure 6 shows the typical range-extension radius that could be expected for an airborne platform when communicating to ground terminals with antennas that have elevation angles of 0°, 5°, 10°, 20° and 30°. An elevation angle of 5° should be considered to be the minimum for an antenna at sea level. The problem is not so marked for VHF and UHF whip antennas, which tend to have an omnidirectional radiation pattern.

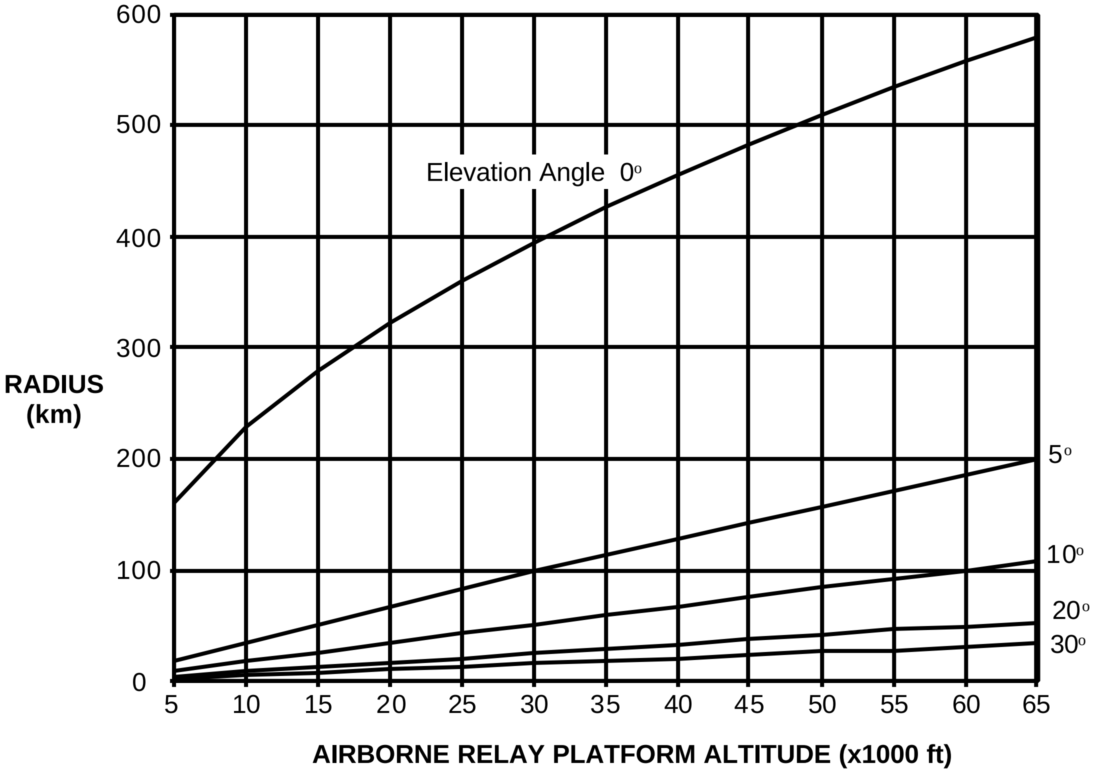

Figure 6: Airborne Range Extension Radius for Various Antenna Elevation Angles[8]

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8 T. W. Mahoney, Annex A to M. J. Ryan and M. R. Frater, *Battlespace Communications System (Land) Architecture Study*, ADF Contract CAPO 3726441, October 1999.

Effects of Weather on Propagation

While weather will have a small effect on propagation to and from the airborne platform, that effect is either negligible or easily accommodated. At high frequencies (above 1 GHz), propagation to and from the airborne platform will suffer attenuation by rain, cloud and so on as the radio wave passes through the troposphere. However, most communications frequencies for the Combat Radio and Tactical Trunk Subsystems will be below 1 GHz and will therefore not suffer any additional loss due to weather. Frequencies above 1 GHz (such as for surrogate satellite communications) will suffer some loss (of the order of 1–2 dB) and will therefore require slightly larger transmit-powers and higher-gain antennas. However, these difficulties will be much fewer than those experienced for satellite communications since the airborne platform is twenty to 2000 times closer than communications satellites.

Tactical Vulnerability

One argument often targeted against airborne communications platforms is their supposed vulnerability against air attack. Attrition rates for UAVs are generally accepted to be higher than those for manned aircraft. The performance of the air vehicle is optimised in terms of cost, size and weight, and there is little room for system redundancy within the airframe. The kill probability of the air vehicle, when hit, is very high. However, it appears that a UAV is difficult to hit either with gunfire or a missile. Aerostats in particular present a difficult target, as two Canadian F16s recently found to their chagrin when trying to shoot down a wayward aerostat that had wandered into controlled airspace. At greater heights such as 20 km, where conventional fighter aircraft struggle to operate, an airborne platform is relatively safe against conventional attack.

The platform is also potentially vulnerable to electronic attack of its communications platform, command links or navigation systems. However, measures can be taken to minimise vulnerability to electronic threats, and in this regard the vulnerability of the airborne platform is no greater than that of any other electronic battlefield asset.

These issues are generally irrelevant when the operational environment is considered. An airborne platform has its greatest utility in extending communications ranges when the supported force is dispersed. If the force is dispersed, then it must be assumed that air superiority has been attained, in which case the airborne platform is not vulnerable. The corollary is that, if air superiority has not been attained, the force will not be dispersed and the requirement for an airborne platform is not so great.

Technical Challenges

All the radio frequency systems that are intended to be mounted on an airborne platform create considerable spectrum conflict. For example, the US ACN proposes to have twenty combat-radio channels when only four can currently operate simultaneously. In all, the platform must deal with more than seventy-five collocated transceivers with seventeen different waveforms, with the entire capability designed to fit into 100 cubic feet, weigh no more than 450 pounds and consume only 5 kW of power.[9]

Other problematic issues are antenna design for an airborne platform; the provision of control, switching and networking services; management of encryption algorithms and keys; and size and weight restrictions, which will only be met with the development of smaller, lower-power electronics.

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[9] R. K. Ackerman, 'Defense Department Researchers Aim for Sky-based Switchboards', *Signal*, April 1999.

PAYLOAD ARCHITECTURE

Overview

Figure 7 shows a proposed upper-level view of the payload architecture on board the airborne platform.

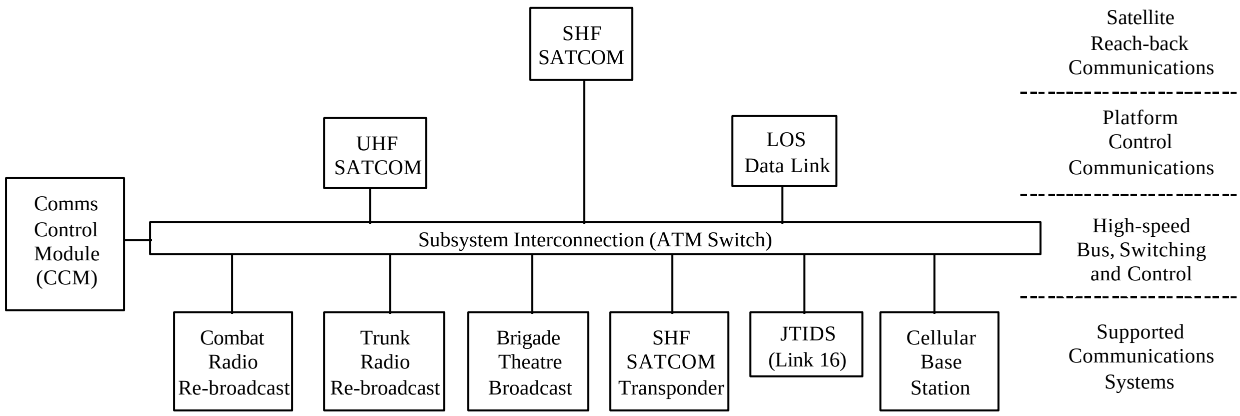

Figure 7: Upper-level view of the Tactical Airborne Subsystem's payload architecture

The payload comprises four main elements:

- **Satellite Reach-back Communications.** This SHF satellite communications system provides a data (and potentially control) communications from the AO to the strategic network.
- **Platform Control Communications.** The airborne platform can be controlled by either UHF satellite communications or direct LOS radio.
- **High-speed Bus, Switching and Control.** The airborne platform provides a high-speed data bus to interconnect each supported communications system. Also on board is a high-speed switch, probably based on asynchronous transfer mode (ATM) technology. This element also contains the Communications Control Module (CCM), which is capable of changing the operating parameters of the on-board communications systems.

- **Supported Communications Systems.** These elements provide the services to supported communications subsystems, including combat radio and trunk radio rebroadcast, brigade theatre broadcast, surrogate satellite communications, Link-16 repeater and cellular base-station.

Communications Control Module

The Tactical Airborne Subsystem must include a CCM that is capable of changing the operating parameters of the on-board communications systems (such as switching frequencies, hop sets, and cryptographic variables). These parameters should be able to be pre-programmed before deployment as well as by remote control from the ground during operation.

An on-board CCM would increase the number of gateways to provide truly seamless connectivity to link users of dissimilar systems. The CCM is perhaps the most crucial capability for proper operation of the Tactical Airborne Subsystem. The CCM must perform the following functions:

- provide interconnection between all on-board communications services and equipment;
- manage in-flight service priorities, frequency assignment, net initialisation, communications security (COMSEC) key assignment, and antenna pointing;
- dynamically access and reallocate unused communications channels on the airborne platform; and
- provide gateway connectivity and data format conversions between subsystems.

POTENTIAL PLATFORMS

Platform Type

There are three main potential platforms for the Tactical Airborne Subsystem:

- piloted aerial vehicles;
- UAV; and
- aerostats (balloons).

While piloted airborne communications platforms were employed during World War II and other conflicts such as the Vietnam War, UAV and aerostat platforms have generally been considered somewhat eccentric. However, a number of commercial consortia—such as Angel Technologies, Sky Station, Astrolink, EuroSkyWay, SkyBridge and Teledesic—are currently developing systems in competition with broadband satellite-based projects. Compared with these space-borne solutions, subspace platforms offer the significant advantages discussed at the beginning of this paper.

Piloted Aerial Vehicles

The most conventional solution is to mount suitable communications packages in a piloted platform. As an example, Annex A provides a brief description of the Angel Technologies' High-altitude Long-operation (HALO) system.

The HALO system comprises a fleet of specialised Proteus aircraft that carry broadband transponders communicating through a large underbelly antenna. The piloted aircraft is designed to orbit for up to 16 hours at a time at approximately 16 km, providing a variety of fixed and mobile wireless services including voice, data and video. Plans are well advanced, with an

August 1999 trial aircraft achieving a 52 Mbps wireless link with the ground.[10]

Uninhabited Aerial Vehicles

There is considerable worldwide development of UAV-based platforms, predominantly for surveillance operations. UAV-mounted sensors on platforms such as Predator and Phoenix have provided valuable information in theatres such as Bosnia. Attention is now turning, particularly in the US, to the employment of UAV in a communications and electronic-warfare mode.

As an example of an UAV-based communications solution, Annex B describes the US ACN concept, which proposes to use the Global Hawk aircraft as a platform.

Other international programs include NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program, which is aimed at developing high-altitude solar airplanes capable of continuous flight for months at a time at altitudes of over 60,000 ft. Applications for such aircraft include telecommunications, reconnaissance and atmospheric measurement. ERAST airplanes have included the Pathfinder and Centurion aircraft built by AeroVironment in the US. AeroVironment have also built the 2 000-pound Helios platform that is scheduled to fly in mid 2001.[11]

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10 T. Edwards, 'More Than Just Hot Air', *Communications International*, September 1999.

11 Further information on Helios and associated programs can be found in:
F. Sweeney, "Sun-powered Aircraft Could Propel Telecommunications to New Heights", http://www0.mercurycenter.com/sctech/news/indepth/docs/solar101700htm (Downloaded 30 March 2001).
"AeroVironment Unmanned Aerial Vehicles", http:// www.aerovironment.com/area-aircraft/unmanned.html (Downloaded 30 March 2001).

Aerostat Platforms

An alternative to UAV is provided by *aerostats*, which are also called *dirigibles* or *balloons*. Several commercial consortia propose to use aerostats as the platforms for metropolitan coverage for broadband services. For example, Sky Station International of Washington DC[12] plans to have aerostats aloft from 2000. The company plans to have 250 helium-filled balloons hovering 21 km above the world's biggest cities.

Similarly, the Japanese Ministry of Posts and Telecommunications has advanced plans for an aerostat-based broadband access network. Another system is being developed by Turin Polytechnic in conjunction with the Italian Space Agency. This long-endurance platform will be powered by solar energy during the day and fuel cells at night.[13]

As an example of an aerostat-based solution, Annex C briefly describes Sky Station's Stratospheric Telecommunications Service concept.

Tethered Aerostats. Most modern aerostats are tethered, that is, they are tied to the ground. Tethered aerostats have found particular application in elevating sensors and are used in surveillance tasks in such locations as the US–Mexico and Iraq–Kuwait borders. However, tethered aerostats tend to have limited ranges due to their low altitudes of around 17 500 ft (constrained by the technology of the tethering cable and weather conditions). The effects of these range restrictions are discussed in the following section.

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[12] 'Telecommunications Service Characteristics', Sky Station, http://web.skystation.com/service.html (Downloaded 17 April 2000).

[13] T. Edwards, 'More Than Just Hot Air', *Communications International*, September 1999.

Disposable Balloons. Scientists at the Defence Science and Technology Organisation have demonstrated the feasibility of releasing a low-cost ($1000) disposable meteorological balloon carrying a small transponder to provide short-term (two to three hours) over-the-horizon communications. This concept was originally developed for the Royal Australian Navy, but it has promise for tactical units to extend VHF–UHF coverage temporarily.

Platform Height

The previous analyses have been conducted assuming a stratospheric (subspace) altitude of 21 km (65 000 ft). However, an airborne platform could potentially operate at any height.

Table 1 shows some UAV programs that offer possible solutions to requirements for the Tactical Airborne Subsystem.

As can be seen from the table, the lower the altitude, the shorter is the communications range to ground terminals. More platforms would therefore be required to cover a particular AO. Additionally, a larger number of platforms would be required to maintain 24-hour coverage due to the shorter endurance.

Global Hawk is also self-deployable worldwide, whereas the others are not self-deployable and would require considerable in-theatre infrastructure to maintain operations. In particular, a suitable airstrip would be required. These smaller assets would therefore be deployed by uniformed personnel, as opposed to Global Hawk, which could provide a tactical service but have the logistical advantages of operating from civilian airports in the strategic environment, and be repaired and maintained by civilian personnel.

Platform	**Tier II+ 'Global Hawk'**	**Tier III 'Dark Star'**	**Tier II 'Predator'**	**Tactical UAV 'Outrider'**
Endurance	42 hours	8+ hours	40+ hours	3 hours
Range	5 500km / 24hours / 5 500km	900km / 8hours / 900km	900 km	185–230 km
Loiter altitude	65 000 ft (above commercial airspace)	45 000 ft (above commercial airspace)	25 000 ft (in commercia l airspace)	13 000 ft (in commercial airspace)
Footprint diameter	500–650 km	400 km	300 km	150 km
Payload	900 kg	>350 kg	200 kg	35 kg

Table 1: UAV Programs Offering Possible Platforms for Tactical Airborne Subsystem[14]

Additionally, an asset that can perform as the Tactical Airborne Subsystem will require the larger payload capacity of Global Hawk. The services detailed in earlier sections could not be provided by the smaller platforms, which would only be able to provide range extension for a few combat radio channels.

Larger platforms operating at greater altitudes (approximately 65 000 ft) are therefore preferred as the basis of the Tactical Airborne Subsystem. The deployment of a larger number of less-capable systems is not likely to be cost-effective.

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14 *Warfighter Information Network (WIN) Master Plan*, Version 3, US Army Signal Center and Fort Gordon, Fort Gordon, GA, 3 June 1997.

COSTS

In the absence of detailed user requirements, accurate costs are currently difficult to estimate and compare for each potential platform. However, the following indicative costs allow some basis for comparison.

The US ACN is currently under design by three US teams headed by Raytheon, Sanders and TRW. The Defence Advanced Research Projects Agency believes that a full fly-away capability can be achieved for less than US$5 million per aircraft unit. Taking into account full operating costs, Australian estimates for Global Hawk life-cycle costs (one platform and ground equipment) are approximately $1000 million over ten years (acquisition cost and seven years operating costs).[15] For a smaller platform, estimates for thirteen Predator-based platforms are US$18 million over the fiscal years 1997 to 2002.[16]

Although difficult to quantify precisely, costs for aerostat-based solutions are expected to be at least half that of UAV solutions, depending on the desired mission profiles. For example, the total investment for the Turin Polytechnic/ISA platform is expected to amount to only about US$3 million and the operating cost might be as low as US$345 per hour. This investment is at least an order of magnitude[17] lower than that required for land-based terrestrial

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15 G. Hale, *ADF Employment of the Global Hawk Uninhabited Aerial Vehicle (UAV)*, Air Power Studies Centre, Paper no. 76, Royal Australian Air Force, Fairbairn, ACT, July 1999.

16 C. A. Robinson, 'High-capacity Aerial Vehicles Aid Wireless Communications', *Signal*, April 1997.

17 'Order of magnitude' is a term in common use in engineering. One order of magnitude means a factor of 10; two orders of magnitude mean a factor of 100; three orders mean a factor of 1000; and so on.

broadband distribution systems and two orders of magnitude less than that required for satellite-based platforms.[18]

CONCLUSIONS

The Tactical Airborne Communications System provides a significant improvement in communications ranges by extending the Combat Radio, Tactical Trunk and Tactical Data Distribution Subsystems. In addition, it allows for command and control on the move across an AO with a radius of between 200 and 500 km. The deployment of an airborne platform offers additional opportunities in the provision of other communications services such as theatre broadcast and PCS.

Despite the need to resolve a number of technical challenges, there are a number of potential subspace platforms that will be able to meet the requirements of a Tactical Airborne Subsystem in support of land operations. The precise platform type and payload will depend on the nature of the operational requirement, but it is considered that the larger systems have the most potential due their larger capacities and higher operating altitudes, leading to longer ranges for communication range extension.

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[18] T. Edwards, ‘More Than Just Hot Air’, *Communications International*, September 1999.

ANGEL TECHNOLOGIES' HIGH-ALTITUDE LONG-OPERATION SYSTEM[19]

As an example of a solution based on a piloted vehicle, this annex briefly outlines Angel Technologies' High-altitude Long-operation (HALO) system.

Introduction

Angel Technologies Corporation and its partners (Endgate Corporation, Scaled Composites, and Wyman-Gordon Company) propose a piloted HALO aircraft with a fixed-wing airframe and twin turbofan propulsion (see Figure A-1) that will operate above 52 000 ft over selected cities. Angel Technologies plans to start leasing services from 2001.

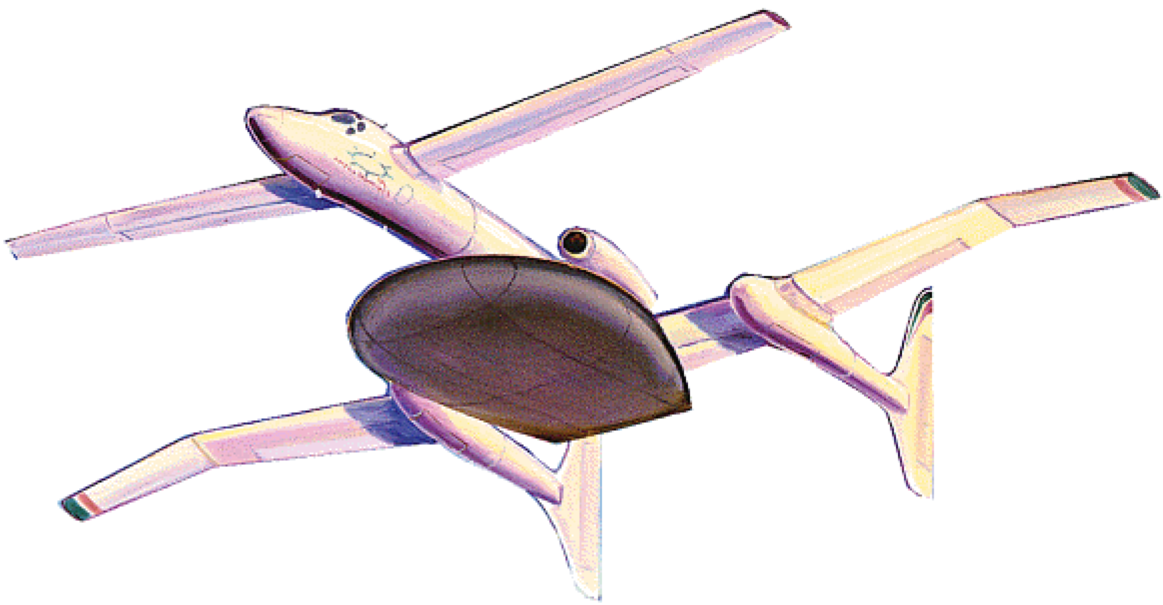

Figure A-1: The HALO *Proteus* Aircraft Built by Scaled Composites

[19] The information in this annex is based on details located at the Angel Technologies' web site: http://www.broadband.com/, unless otherwise noted.

Platform

The HALO *Proteus* aircraft (being manufactured by Scaled Composites, a division of Wyman–Gordon Company) will be certified by the Federal Aviation Administration (FAA) for piloted commercial operation and can operate from any regional airport within a 500 km radius of the city to which communications are provided. The HALO Proof-of-concept aircraft flew publicly on 21 September 1998 and is currently undergoing flight trials. Proteus is built from composite materials and has a gross weight of 6.4 tonnes, including 2.8 tonnes of fuel. Seating is available for two pilots (as well as a spare seat for a third pilot or passenger). Two pilots will be used in the short term to streamline FAA approval; in the long term, one pilot or even an uninhabited vehicle may be employed.

The aircraft has an on-station endurance of 12 hours and can operate up to a ceiling of 64 000 ft. However, typically, the platform will fly at 51 000 ft and will remain on station for up to eight hours, dictated mainly by pilot endurance. Each HALO location is serviced by a fleet of three HALO aircraft providing one aircraft on-station at any time. The aircraft orbits at a diameter of 9–15 km and uses GPS to maintain its position within 100 m.

The aircraft will carry nearly 900 kg of payload, including an antenna array and electronics, in a large, streamlined pod underneath. The pod is roll-stabilised so that it swivels to remain parallel to the earth as the aircraft banks. The antenna array creates hundreds of contiguous virtual cells on the ground to serve thousands of users. The liquid-cooled payload can be provided with greater than 40 kW of direct-current power.

Ground Station

The ground stations are relatively simple, although a steerable antenna is required because the ground station must track the aircraft that is orbiting at a diameter of 9–15 km.

Broadband Services

The HALO aircraft will provide the hub of a star-topology broadband telecommunications network that will allow subscribers to access multimedia services, the Internet and entertainment services as well as to exchange video, high-resolution images, and large data-files. Information addressed to non-subscribers or to recipients beyond the region served by the HALO Network will be routed through a dedicated HALO Gateway connected to the public switched networks, or via business premise equipment that is owned and operated by service providers connected to the public networks.

The communications payload will operate in two 300 MHz portions of the 28 GHz band. Individual consumers will be able to connect at rates ranging from 1 to 5 Mbps. Business users will be offered connection speeds ranging from 5 to 12.5 Mbps, although some initial high-capacity users may be able to operate links at 25 Mbps and higher. Angel Technologies claim that between 10 000 and 75 000 1.5 Mbps channels can be supported within a 96 km diameter area.

US AIRBORNE COMMUNICATIONS NODE[20]

As an example of the UAV-based solution, this annex outlines the US ACN concept.

The ACN combines the capability of a high-altitude endurance UAV with the essential capabilities of a state-of-the-art communications package (node). The ACN's capability to self-deploy anywhere in the world will free up airlift assets that can be used for other missions. The ACN will carry robust communications packages that can be reconfigured rapidly to support changing command and control (C2) priorities. High-gain antennas, coupled with the ACN's ability to loiter at very high altitudes (65 000 ft and higher) for extended periods of time, will enable tactical users equipped with lightweight omnidirectional antennas and low-powered radios to establish over-the-horizon communications from mobile platforms. This capability will provide a significant improvement in C2 on the move.

The ACN will be a uniquely capable platform for greatly improving battle command and battle management communications. The ACN's lift capacity will allow it to carry a large, multi-band, multi-mode and robust communications payload to support a relatively large number of subscribers. Some of the possible communications payloads are:

- Tactical Command, Control, and Communications (C3);
- Communication Control Element (CCE);
- Mobile Subscriber Equipment (MSE) Trunk Network Range Extension Radio (MSE RER);

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[20] This annex is largely an extract of the ACN description in *Warfighter Information Network (WIN) Master Plan*, Version 3, US Army Signal Center and Fort Gordon, Fort Gordon, GA, 3 June 1997.

- Global Broadcast System with Common Data Link (CDL) capability; and
- Link-16.

The capability to operate at high altitudes will provide a large communications footprint diameter of 400–650 km (depending on ground systems deployed). Loiter endurance times of 24 to 96 hours or more will help ensure access by users. A robust antenna and power suite will support the integration of leap-ahead information and communications technology as it becomes available, without major modifications to the airframe, antennas, or power bus. As illustrated in Figure B-1, the objective ACN will be fully modular, with a common power and signal bus, and a flexible antenna system. This will allow rapid reconfiguration between missions.

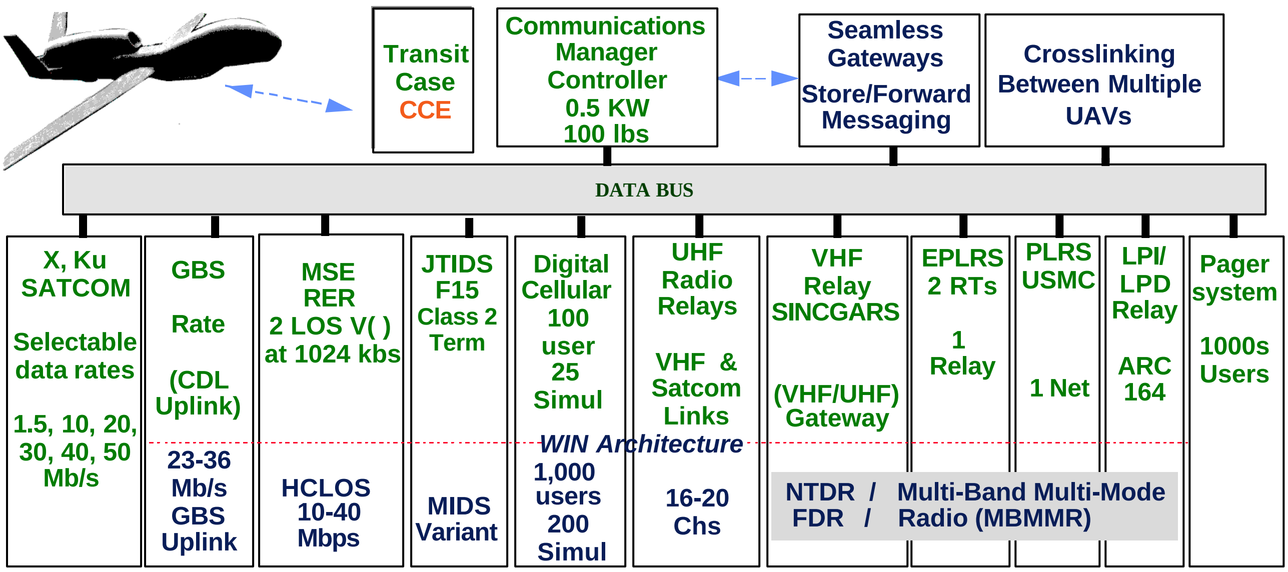

Figure B-1: Objective Capabilities for US Airborne Communications Node (ACN) [21]

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[21] *Warfighter Information Network (WIN) Master Plan*, p. 5-9.

The objective ACN system will provide communications capabilities to support existing joint and Army communications architectures, and to correct communications deficiencies identified during recent deployments and operations. The ACN capability should include the communications facilities illustrated in Figure B-2.

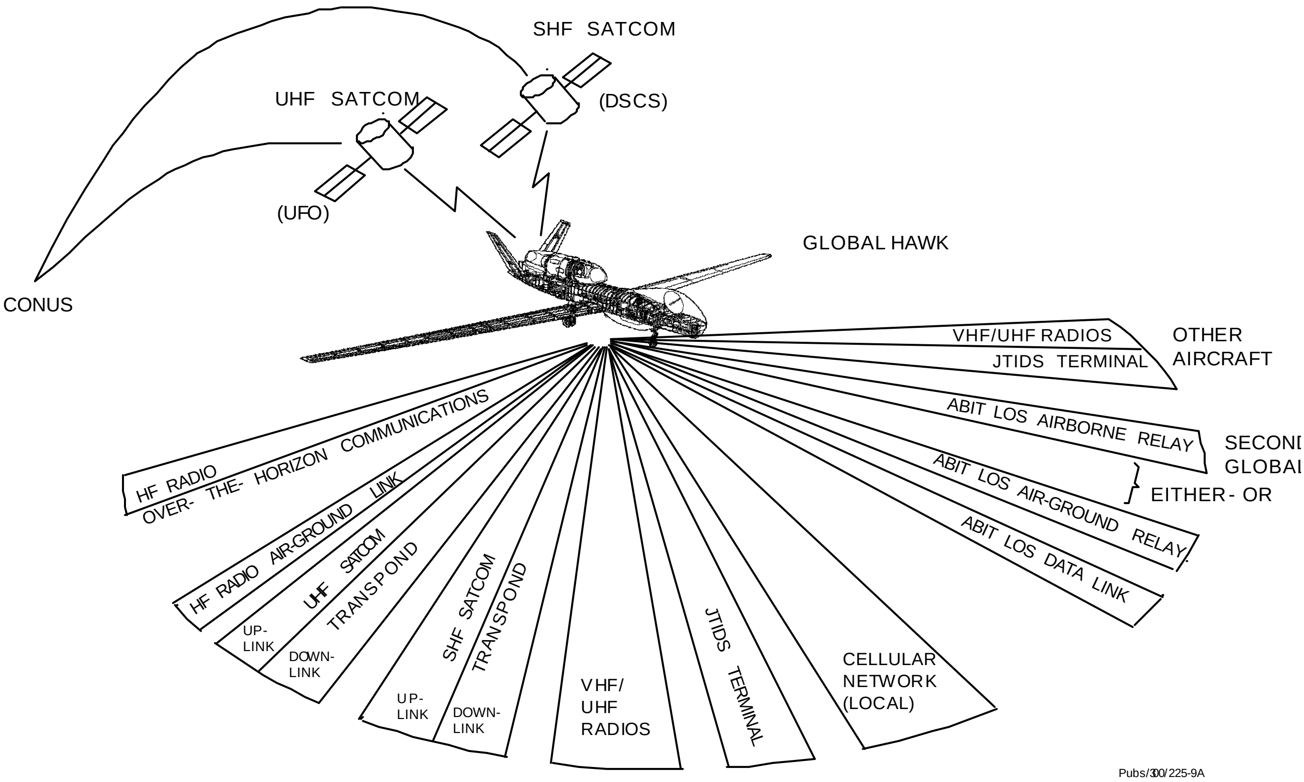

Figure B-2: US ACN Payload[22]

As an essential part of the Warfighter Information Network (WIN), the ACN contributes to the rapid connectivity of the entire network. The force projection capabilities of the ACN will greatly enhance the communications capabilities of the WIN architecture. The ACN will provide reach-back connectivity from the area of

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22 TRW Report, UAV Communications Payload Study, CDRL No. A148 — Final Report, p. 9.

operations to sustaining bases. It will also provide gateways for seamless communications between dissimilar communications systems. The ACN will provide communications redundancy to ensure information dominance, reduce the requirement for terrestrial line-of-sight radio relays, and provide new types of communications services directly to the warfighter.

Although the ACN augments commercial and military satellites, it does not replace them. Satellites and satellite radio systems operate in specific frequency bands and provide unique communications services to support WIN. Satellites will not, however, have the capability to support range extension for every type of military radio and communications system. Range extension for voice and data line-of-sight communications through the ACN will enhance the warfighter's C2 capability.

The ACN System will provide communications capabilities to support existing joint and Army communications architectures, and to correct communications deficiencies identified during recent deployments and operations. The ACN will include the following capabilities:

- A modular communications node payload will be included with gateway capability to support and interconnect a joint task force (JTF), corps or division that has both legacy and state-of-the-art communications systems.

- A robust antenna system, versatile power suite, and modular communications package will be incorporated to support rapid reconfiguration on a mission-by-mission basis, as communications priorities change. All components on the ACN should be capable of integrating leap-ahead technology as it becomes available.

- Range extension (retransmission) of SINCGARS combat net radio, EPLRS, UHF surrogate satellite, MSE and Link-16 will be provided. A limited gateway capability between SINCGARS and UHF satellite will also be provided. Range extension implies the following requirements:
  - The ACN must be capable of performing retransmission for CNR/SINCGARS nets. An airborne gateway between SINCGARS and UHF single-channel tactical satellite (TACSAT) equipment will provide on-the-move capability for mobile platforms, without the need for high-profile, directional auto-track TACSAT antennas.
  - Link-16 provides information about near-real-time air-defence engagement operations. This information must be accessible by air defence artillery (ADA) units during all phases of an operation. Link-16 relay capability will extend connectivity between widely dispersed ADA task-force elements and the joint air-battle players. The ACN will augment other Link-16 relay, including Airborne Warning and Control System (AWACS), in providing Link-16 range extension.
  - EPLRS is used to broadcast situation awareness data. The relay will link enclaves that are beyond line of sight.
  - MSE relay will connect widely dispersed signal nodes on the battlefield.
- A reach-back capability will be provided for digital cellular phones, to support early entry and major offensive operations. (Cellular phone services may be limited because commercial cell sites are large and heavy, and there is at present no incentive for the commercial industry to downsize.) Reach-back communications will consist of a satellite link with a minimum data rate of T1 (1.544 Mb/s).

- The ACN will also include a Communications Control Element (CCE) capable of switching frequencies, hopsets, and crypto variables by remote control from the ground. An on-board capability will allow for pre-programmable frequencies, hopsets, and crypto variables as well as over-the-air rekey (OTAR) of hopsets and crypto variables.

- An on-board Communications Manager/Controller (CMC) will be supplied to increase the number of gateways that will provide truly seamless connectivity to link users of dissimilar systems. The CMC is perhaps the most crucial capability for proper operation of the ACN. The CMC must perform the following functions:

  - ensure interconnection between or among all on-board communications services and equipment;

  - manage in-flight service priorities, frequency assignment, net initialisation, communications security (COMSEC) key assignment, and antenna pointing, with input from ground controllers of ACN;

  - be responsive (external to any resident control logic) to the ground controllers of the ACN payload, not to the airborne platform controllers;

  - dynamically access and reallocate unused communications channels on the ACN; and

  - provide gateway connectivity and data format conversions for dissimilar joint radio systems (for example, Link-16 to EPLRS, and Havequick II to EPLRS);

- Range extension will be provided for Army and joint videoconferencing for all services.

- The ACN will incorporate low-probability-of-interception (LPI) and low-probability-of-detection (LPD) communications, and store and forward email for special forces and conventional elements that operate deep in enemy territory.
- A Global Broadcast System (GBS) relay will also be included to provide broadcast communications on the move to support tactical users with omnidirectional antennas and low-powered receivers. Nuclear, biological, and chemical (NBC) warnings can be uplinked to the ACN and rebroadcast to miniature pagers on the ground.
- The ACN will contain a fly-away transit case UAV Launch and Recovery Element (LRE). This miniaturised LRE can deploy early in a contingency operation, and allow in-theatre mission controllers to direct the ACNs.
- Cross-linking between multiple ACNs will provide the facility to cover an entire theatre of operation.
- The ACN must operate in secure and non-secure modes.
- The ACN must ensure interoperability with joint architectures.
- The system must be compatible with WIN protocol and standards for switching and subscriber services.

As an essential part of WIN, the ACN contributes to the rapid connectivity of the entire network. The force projection capabilities of the ACN will greatly enhance the communications capabilities of the WIN architecture.

The ACN will provide:

- reach-back connectivity from the area of operations to sustaining bases;

- gateways for seamless communications between dissimilar communications systems;
- communications redundancy to ensure information dominance; and
- new types of communications services directly to the warfighter.

The ACN will also reduce the requirement for terrestrial line-of-sight radio relays

SKY STATION'S STRATOSPHERIC TELECOMMUNICATIONS SERVICE[23]

As an example of an aerostat-based solution, this annex briefly describes Sky Station's Stratospheric Telecommunications Service concept.

Introduction

The Sky Station's uninhabited aerostat platforms (see Figure C-1) are guided under remote control on an ascent path to the stratosphere, where GPS is used to locate the platform precisely in the desired geostationary position. The platform then remains in that position for up to ten years, providing high-speed, high-capacity wireless broadband services to an area of approximately 19 000 km^2. Remote sensing and monitoring devices can also be installed on the platform, providing invaluable continuous data collection.

An illustration of the Sky Station aerostat is shown in Figure C-1.

Figure C-1: The Sky Station Aerostat

[23] Unless otherwise noted, the information in this annex is based on details located at the Sky Station web site: http://www.skystation.com.

The US$7.5 billion plan is to offer wireless communication services to users of laptops and hand-held terminals at speeds of 64 kbps to 2 Mbps. The stations will probably accommodate anywhere from 50 000 to 150 000 communications channels, although the theoretical limit for the network is 650 000 64-kbit/s channels, according to Sky Station.[24]

The Stratospheric Telecommunications Service is planned to commence with the first Sky Station platform deployment in 2002. Subsequent Sky Station platforms will be implemented in accordance with user demand. Ultimately, Sky Station plans to have at least 250 Sky Station platforms, one above every major city in the world. Additional platforms may be located above large population centres, such as Tokyo or London, and additional platforms can be added at any time to increase capacity over specific regions.

Sky Station's company officials include former US Secretary of State and NATO commander Alexander P. Haig and his son. The Sky Station industrial team includes Lockheed Martin Global Telecommunications as the end-to-end system integrator; Alenia Spazio/ Finmeccanica of Italy as the primary payload developer; Dornier Satellitensysteme GmbH of Germany (a corporate unit of DaimlerChrysler Aerospace) as a developer for the power subsystem; Airship Technologies Services Ltd of the United Kingdom as the prime contractor for the platform; Thomson-CSF Communications of France as gateway earth station manufacturer and payload subcontractor; and United Solar Systems Corp. of Michigan, USA, as supplier of lightweight solar cells.

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24 'A Real Trial Balloon', CMP Media Inc., http://www.teledotcom.com/0197/fetures/tdc0197satelliteside1.html, January 1997 (Downloaded 17 April 2000).

Platforms

The size of Sky Station platforms depends on market demand or the services on board. The average platform will be approximately 157 m long and 62 m in diameter at the widest point (about as wide as a football field and 1.7 times as long). The platform is equipped with sufficient solar and fuel cell capacity to carry a payload of up to 1000 kg.

Although designed for a lifespan of 5–10 years, platforms can be recalled for repair if necessary. A new platform will be deployed in advance to replace the existing one so that there will be no interruption of service. Catastrophic rupture of the main hull is unlikely due to the use of state-of-the-art envelope materials and weaves. However, in the event of a loss of buoyancy, the automated master control system can propel the platform to a safe water-landing.

Communications Services

Sky Station's stratospheric platforms are ideally suited to delivering telecommunications services. Broadband and mobile communications services can be provided at low cost with low latency (less than 0.5 ms compared to about 250 ms for GEO-based services). Additionally, no handover is required for mobile communications. Handover is a significant design issue in terrestrial systems and causes many problems in LEO-based services.

Broadband Services

The Stratospheric Communications Service promises to provide cheap, easy access to broadband services in direct competition with the more expensive terrestrial and satellite-based solutions. Subscribers transmit directly with the platform, where on-board switching routes traffic directly to other Sky Station subscribers within the same platform coverage area. Traffic destined for subscribers outside the platform coverage area is routed through ground stations to the public networks or to other platforms serving nearby cities.

With data rates of up to 2 Mbps uplink and 120 Mbps downlink, subscribers will be provided with high-speed Internet access, as well as other broadband services such as television distribution, videoconferencing, and on-line remote monitoring and other security applications.

Spectrum in the 47 GHz band (47.2 – 47.5 GHz stratosphere-to-earth and 47.9 – 48.2 GHz earth-to-stratosphere) has already been designated globally by the International Telecommunications Union (ITU) and the Federal Communications Commission (FCC) for use by high-altitude stratospheric platforms, paving the way for planned commercial service to commence in the year 2000.

In addition to markets in developing worlds, Sky Station has significant potential in developing countries, where the stratospheric platforms provide the fastest, easiest and least-expensive way to introduce advanced communications services. One Sky Station platform alone provides a telephone service for millions of subscribers at a lower cost than any current or proposed system.

Table B-1 gives technical details of Sky Station's planned 47 GHz broadband services.

Mobile Communications

The Sky Station system is also the ideal means for low-cost, rapid deployment of mobile services. Sky Station is participating in the development and delivery of a third-generation cellular service. Technical details of a typical system are shown in Table B-2.

47GHz BROADBAND TECHNICAL DETAILS	
PLATFORM	
Platforms:	250 platforms worldwide, each operating independently through ground stations and existing public networks. Future platforms will have platform-to-platform links.
Altitude:	21 km (70 000 ft)
Coverage Area:	150 km diameter; 19 000 square kilometres plus specified locations outside this zone
Spot beams:	700 spot beams per platform
Angle of Elevation:	>15°
SPECTRUM	
Uplink/ Downlink:	100 MHz in 47.9 – 48.2 GHz / 100 MHz in 47.2 – 47.5 GHz
SIGNALLING PROTOCOL	
Modulation:	QPSK (subscriber); 64QAM (ground station)
Communication protocol:	FDMA/TDMA uplink, TDM downlink
SUBSCRIBER INFORMATION	
Data rate:	2Mbps uplink/10Mbps downlink
Power requirements:	100–250 mW

Table B-1: Technical Details of Sky Station's Planned 47 GHz Broadband Services[25]

Earth-science Applications

Sky Station platforms also provide an ideal vehicle for a range of earth-science applications. Stratospheric sensors could provide high-resolution imagery within the platform's footprint, offering high-quality information to monitor weather; stratospheric chemical composition; all types of atmospheric, land and sea pollution;

[25] 'Telecommunications Service Characteristics', Sky Station, http://web.skystation.com/service.html (Downloaded 17 April 2000).

energy efficiency; electromagnetic radiation; traffic patterns; search and rescue; and so on.

TYPICAL 2GHZ SKY STATION SYSTEM	
INFRASTRUCTURE	
Platforms:	One platform with several ground stations per metropolitan area
Altitude:	21–23 km
Coverage Area:	1000 km diameter footprint
Spot beams:	>1000 spot beams per platform
Capacity:	2.06 Gbps capacity dynamically spread across footprint, Equivalent of 425 000 simultaneous 8.0 kbps telephone calls with 50% voice activity
SPECTRUM	
Subscribers:	5 MHz (up) and 5 MHz (down) — frequencies identified by the WRC for use with Third-generation Mobile Systems. (1885–1980 MHz, 2010–2025 MHz, and 2110 MHz in Regions 1 and 3, and 1885–1980 MHz and 2110–2160 MHz in Region 2).
SIGNALLING PROTOCOL	
Modulation:	QPSK
Multiple access:	Wideband CDMA
Communication protocol:	Multiple protocols at transport and network levels supported
SUBSCRIBER INFORMATION	
Data rate:	8–16 kbps for voice; 384 kbps for data
Power requirements:	25 mW

Table B-2: Technical Details of Sky Station's Proposed Mobile Communications System[26]

[26] 'Telecommunications Service Characteristics', Sky Station, #2GHz (Downloaded 17 April 2000).

An airborne relay can effectively connect to units operating in mountainous area, where terrestrial radio communications are typically masked and screened by the terrain. The CRP operates in the UHF/VHF bands, supporting a variety of frequencies and waveforms, including Single-Channel Ground-Air Radio System (SINCGARS), extending the range between users for voice and data communications, including chat text, instant messaging and imagery. Harris-supplied Falcon III radios have been operating in Shadow 200 unmanned aerial vehicles (UAVs) as part of an airborne relay system, extend the distance In my new book, â€œThe Future of Land Warfareâ€ (Brookings Institution Press, 2015), I attempt to debunk the new conventional wisdom (which began with the Obama administration but also permeates thinking beyond): Messy ground operations can be relegated to the dustbin of history. That is a paraphrase and dramatization, to be sureâ€”but only a modest one, since the administrationâ€™s 2012 and 2014 defense plans both state that the U.S. Army will no longer size its main combat forces with large-scale counterinsurgency and stabilization missions in mind. This is, I believe, a major conceptual mistake, e