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Range Extention Techniques Available to the Army Tactical Communications System

W.D. Blair and R.E. Dickinson

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ABSTRACT

The adoption of the Network Centric Warfare (NCW) philosophy for Land Force operations means that connectivity through networked communications, typically wireless for mobile operations, is of critical importance. The communications range of the radio equipment becomes a constraint in operational concepts and the degree of implementation of NCW. To overcome this range limitation a series of communications techniques covered by the broad title of 'range extension techniques' enable nodes to communicate within the battlespace through intermediary devices or phenomena. This paper seeks to identify and discuss the broad spectrum of tactical communications network range extension approaches and technologies available. As a result Army will be better informed in the development of communications architectures for deployed Land Force communications.

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Range Extension Techniques Available to the Army Tactical Communications System

Executive Summary

Land force operations can be characterised in any combination of dispersed or conventional operations, in the littoral environment, amphibious and urban or other complex terrain. The adoption of the Network Centric Warfare (NCW) philosophy means that connectivity through networked communications, typically wireless for mobile operations, is of critical importance. The terrain and tactical deployment of the elements of the land force are not conducive to good wireless communications. Consequently the communications range of the radio equipment becomes a constraint in operational concepts and the degree of implementation of NCW. To overcome this range limitation a series of communications techniques covered by the broad title of 'range extension techniques' enables nodes to communicate within the battlespace through intermediary devices or phenomena.

This paper seeks to identify the broad spectrum of tactical communications network range extension approaches and technologies available. Where appropriate it refers/ defers discussion to separate reports that provide greater detail on the technology or platform discussed. In doing this it discusses the constraints on the ranges of communications and considers range extension under the broad categories of: penetration of obstacles in the radio line of sight, the passive 'reflection' of the radio signal, intermediate device techniques and the platforms that carry the intermediary devices. A discussion of the ancillary issues of security, sharing of the relay resources and the problems associated with routing completes this consideration.

Through this analysis of range extension techniques and identification of areas requiring further consideration, Army will be better informed in the development of communications architectures.

Authors

W.D. Blair
Information Networks Division

Bill Blair is a Senior Research Scientist in Mobile Networks Group of the Defence Science and Technology Organisation's (DSTO) Information Networks Division having joined DSTO from the Australian Army. He is involved in research into networking for military strategic and tactical communications.

R.E. Dickinson
Information Networks Division

Rowland Dickinson is a member of the Mobile Networks Group of the Defence Science and Technology Organisation's (DSTO) Information Networks Division. He came to DSTO after a career as a commissioned officer in the Australian Army (Signals) and in private industry management. He is involved in research into communications architectures for and requirements engineering of military (Army) communications. He is currently pursuing a PhD in Applied Mathematics at the University of Adelaide.

Contents

1. Introduction

1.1 Communications Environment

Land force operations can be characterised in any combination of dispersed or conventional operations, in the littoral environment, amphibious and urban or other complex terrain. The adoption of the Network Centric Warfare (NCW) philosophy means that connectivity through networked communications, typically wireless for mobile operations, is of critical importance. The terrain and tactical deployment of the elements of the land force are not conducive to good wireless communications. Consequently the communications range of the radio equipment becomes a constraint in operational concepts and the degree of implementation of NCW. To overcome this range limitation a series of communications techniques covered by the broad title of 'range extension techniques' are sought to enable nodes to communicate within the battlespace through intermediary devices or phenomena.

Figure 1 describes a conceptual land communications architecture as developed for Joint Project 2072 (Battlespace Communications System – Land).

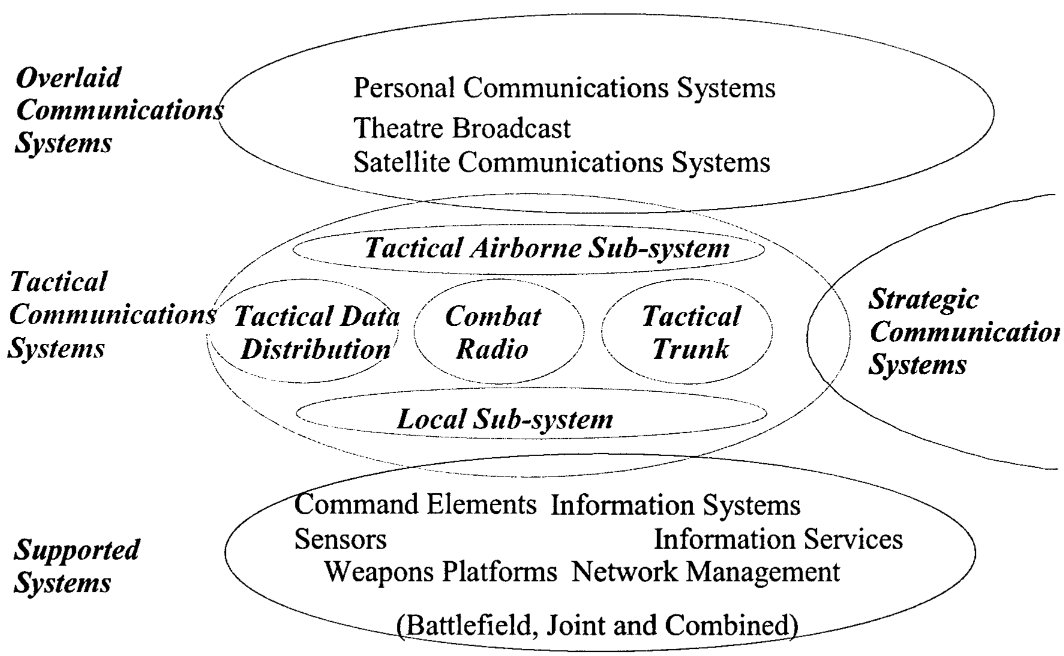

Figure 1:Conceptual Land Communications Architecture.

While the architecture sees a unified logical communications network, several physical bearer networks are envisaged to account for different user needs, especially mobility. The three wide area bearers of Tactical Data Distribution Sub-system, Combat Radio Sub-system and Trunk Sub-systems[1] are all likely to require range extension at times. The Tactical Airborne Sub-systems[2] is envisaged as an elevated relay platform for the three wide area bearers. It will complement other range extension/beyond line of sight communications technologies.

1.2 Purpose of Report

This paper seeks to identify the broad spectrum of tactical communications network range extension approaches and technologies available. Where appropriate it refers/defers discussion to separate reports that provide greater detail on the technology or platform discussed. Through this analysis of range extension techniques Army will be better informed in the development of communications architectures and the use of systems for range extension.

1.3 Structure of Report

Informed discussion of the issues of communications range extension requires an awareness of the constraints on the ranges of communications. These are discussed in the next section. We then consider the broad categories of range extension under the categories of:

- Penetration of obstacles in the radio line of sight.
- The passive 'reflection'[3] of the radio signal to indirectly reach the destination.
- The intermediate device techniques that are available to achieve range extension. This includes discussion of active nodes that are either simply other nodes ('peers') in the network or non-peer devices whose role is dedicated to a relay function as well as technologies that implement them.
- The platforms that carry the intermediary devices based on the environments in which they are located

In the final section of the discussion we consider the ancillary issues of security, sharing of the relay resources and the problems associated with routing as they affect communications range extension.

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[1] The sub-systems are:

- Tactical trunk is generally a converged voice and data network built upon point-to-point links.
- Combat radio is principally a shared frequency voice service with multiple stations sharing a broadcast radio channel (push to talk). Such a service can provide data but it is not optimised for such.
- Tactical data distribution is likely to be a highly dynamic, self-organising (and perhaps multi-hop) data-oriented network, using for instance the US EPLRS and Link technologies.

[2] Note that the Tactical Airborne Sub-system is conceived as providing range extension, not communications to aircraft platforms.

[3] For the purposes of this paper, 'reflection' includes the use of refraction.

Straightforward mechanisms to improve a link, for instance elevating antennae and changing radio parameters such as emitted power, are not considered in this paper as they are well known and practised by Army.

2. Communications Range Constraints

Communications range is determined by the quality of the signal available at the receiver. Quality measures of a communications link include the amount of distortion and interference (particularly from transmissions travelling by multiple paths to the receiver) but arguably the most significant determinant of range in the tactical domain is received signal strength in relation to local noise (Signal to Noise Ratio - SNR). Power losses in the radio path come from a number of phenomena, but for tactical networks this will often be dominated by losses from terrain shadowing, i.e. the link is limited to a range primarily determined by the radio line of sight[4].

Ultimately the range achieved in a radio communications link is determined by the ability to achieve signal quality at the receiver sufficient to sustain the required communications quality. In a digital system, communications quality is principally bit rate (capacity) and bit error rate. Shannon's Law[2] established the upper limit for the capacity of a communications link[5]. While specifically applicable to line/cable communications, in which noise can be considered constant, it provides a convenient mechanism for understanding the potential capacity, and sources for limitations to capacity, of a communications link in general. While emitted bandwidth is a factor in determining capacity[6], a critical value in Shannon's equation is the signal to noise ratio. The key point being that for a given emitted radio bandwidth, the maximum error free bit rate is directly related to the received signal strength and inversely related to the amount of received noise.[7]

In the complex terrain of land operations, the major determinant on the operating range of a terrestrial radio link will be the reduction in received signal from shadow loss, i.e. links will be largely be limited to radio line of sight.

The propagation of radio energy from transmitter to receiver can occur in a number of modes:

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[4] For frequencies at the lower end of the VHF band and below, the radio horizon is different from the visual horizon due to refraction and diffraction effects on these radio frequencies. These effects tend to 'bend' the signal towards the earth resulting in the range being extended beyond the visible horizon[1].

[5] In reality, it is not yet technically feasible to achieve the Shannon's law limit.

[6] Hence the loose use of the term 'bandwidth' in its popularised meaning rather than the more correct description as capacity.

[7] The capacity is also directly related to the emitted radio bandwidth, but this is normally fixed by system or spectrum management constraints.

- Direct wave - when there is no obstruction into radio path, i.e. within radio line of sight.
- Indirect modes can occur where the energy does not follow the radio line of sight between transmitter and receiver:
    - Surface waves are guided along the interface between two different media or by a refractive index gradient. In radio transmission, surface waves (sometimes called 'ground waves') propagate close to the surface of the Earth - the interface between the Earth and the atmosphere. Attenuation (and hence range for a given transmitted power) depends on the conductivity of the ground/water and the polarization of the wave. Range extension employing this mode is achieved through increased effective power (i.e. transmitter power and antenna efficiency) and will not be consider further in this paper.
    - If an obstacle intruding into the line of sight is small compared with the radio transmission wavelength, then some energy is seemingly bent around the obstacle via a diffraction process. This will not be considered further for similar reasons to surface wave.
    - Depending upon the material and the frequency of transmission, radio frequency attenuation may be such that energy can penetrate through obstructions. This is discussed in Section 3.
    - Reflected rays occur when the energy directed towards the ground (or other large surfaces) is reflected, and then collected at the receive antenna. This is discussed in Section 4.1.
    - Refracted (Sky) wave propagation uses the characteristic of repeated refraction of radio waves in the upper atmosphere and is discussed in Section 4.2.
    - Turbulence and or reflective particles in the atmosphere can cause incident waves to be scattered in all directions and is discussed in Section 4.3.

3. Penetration Techniques

Penetration techniques use a number of approaches. An emergent approach discussed in the literature is based on ultrawideband (UWB) technology[8][4][5][6]. The basic concept of UWB technology is to transmit and receive extremely short duration bursts of radio energy. As these bursts are very short, the resultant waveforms are extremely broadband offering potential for high bit rate as well as potentially reducing vulnerability to enemy interception and jamming. The short duration waveforms can be engineered to be less susceptible to multipath[9] effects experienced in mobile and urban environments - the

[8] The Federal Communications Commission of the USA (FCC) defines an UWB device as any device with a -10dB fractional bandwidth, greater than 20% or occupying at least 500MHz of the spectrum [7]

[9] Multipath occurs when radio waves travel from source to destination via many paths such as by reflecting off different obstacles along the way. Under conventional techniques, these multiple

signal pulse is completely received before the interfering signal arrives. In principle, such short pulses would produce radio emission across the entire radio frequency band, but antenna and transmitter/receiver limitations and regulatory issues restrict the actual emitted band. Development of UWB has been constrained to date by regulatory issues. Spectrum planners continue to explore the possible impact on conventional radio uses (in particular Global Positioning System) of widescale UWB deployment.

Depending on the frequencies being emitted, UWB transmissions can penetrate walls and soil. This phenomenon has seen particular application in ground and wall penetrating radars. Such penetration is best achieved at relatively low frequencies (under 1GHz) debarred from civil communications applications by current regulations.

Most commercial developments of UWB have focussed on very short range, very high bit rate indoor wireless local area networks in the 3 to 10GHz region. Manufacturer's statements of penetration of walls for communications use may be optimistic given the high frequency and low power - the propagation mode may indeed be via some surface or multipath means. There have been limited military role developments in the area of using surface wave (VHF) propagation for non line-of-sight operation over tens of kilometre ranges and UWB skywave (HF)[8]. The use of penetration as a propagation mode has not been observed by the authors of this study. Nevertheless, the use of UWB for communications in urban operations/within buildings is worthy of further attention.

4. 'Reflection' Techniques

If direct communications are not possible, then 'reflections' off objects or other phenomena, which appear to the user as reflection, may transfer power to the receiver. Such redirection is essentially a passive action, so power losses remain a challenge to communications.

4.1 Reflection Off Objects

Any object can be used to reflect signals. In the past, approaches have been explored using a single reflector comprising the moon, artificial satellite or aircraft[10]. These examples are not considered further because of difficulties incurred due to inefficient power transfer that calls for directional (and perhaps steerable) antennae and high-powered transmitters/low noise receivers. This report will however consider a new technology

paths cause problems in that the multiple signals will interfere with each other, possibly cancelling each other, or at the very least causing distortions of the received signal.

[10] Suggestions have been made from time to time in the literature that the tails of disintegrating meteors can be used for communications (as contrast to the ionised air of meteor burst systems). Similarly in the popular amateur radio press there are suggestions of the use of the water condensation trails of aircraft or deliberately inserted particles into the atmosphere. While the possibilities are intriguing, no investigations of these phenomena are known of by the authors.

approach to using reflection to overcome fading that may have significant relevance in urban terrain.

Radio communications, particularly in built up areas, can be affected by multipath propagation. Conventional systems seek to equalise or compensate for the multipath. There is also an emerging class of systems under the label of Multiple Input/Multiple Output (MIMO) or Space-Time Coding[11]. These use multiple transmit antennas, multiple receive antennas and associated processing to exploit the multipath and achieve performance improvement over a perfect single path communication[12]. The motivation of most civilian developments is achieving higher capacity and multiple re-use of spectrum that aligns with the high capacity needs required by NCW. Over and above the capacity issue, US DARPA is experimenting with MIMO for its Electronic Protection Measures (EPM) benefits [12][13][14]. The use of MIMO within ADF tactical communications bears further investigation.

4.2 Atmospheric Refraction

4.2.1 HF Skywave Propagation

For frequencies generally in the High Frequency (HF) band an ionised portion of the atmosphere known as the 'ionosphere' can refract the waves back to Earth. The angular deviation induced by the ionosphere depends on the frequency of the wave and the degree of ionisation (which has short term changes atop of diurnal, seasonal and '11 year sunspot cycle' variations). The ranges achieved depend on the geometry involved (i.e. the apparent height of the ionosphere and the angle of the ray being refracted).

Skywave communications have been practised extensively within the Army and so this report will not linger on this range extension means. Suffice to say here that while the advent of digital signal processing and advances in error correcting codes have revolutionised HF link performance, capacity still remains low (no more than tens of kilo-bits per second). Systems such as automatic link establishment and real time frequency management have somewhat eased the traditional need for highly skilled operators with diverse skills.

A threat to skywave communications is the speculation of the overdue occurrence of a period of no sunspot activity such as the Maunder Minimum and earlier Spoorer Minimum[18]. The occurrences of these periods are subject to scientific debate as well as the effects they will have on long-range communications. However, the possibility of a lack of sunspot activity presents the interesting possibility of the disappearance of the ionosphere for practical long-range communications purposes.

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[11] Space-time codes for high data rate wireless communication: performance criterion and code construction. [9]page(s): 744 - 765 and [10]

[12] For a discussion on Bell Laboratories implementation of MIMO (Bell Labs Layered Space/Time – BLAST) see [11]

4.2.2 Tropospheric Ducting

Tropospheric ducting is a specific form of refraction affecting VHF and UHF signals in which the tropospheric conditions result in a refraction of the signal towards the Earth as it moves away from the Earth surface and refraction away from the Earth as it moves towards the Earth. For mid UHF (1GHz) duct depths are around 15 metres and for high VHF (300 MHz) duct depths are around 180 metres. Ranges of ducts are variable but of the order of thousands of kilometres 'one way' have been recorded. As with skywave propagation the presence and nature of ducts vary with diurnal, seasonal and '11 year sunspot cycle' variations that affect the ionisation of the troposphere. Forecasts of 'ducts' are readily available through the Internet (for instance [22]). The use of the phenomenon itself for range extension and the usability of such predictions as an aid for planning would need to be explored.

4.2.3 Meteor Burst

Meteor Burst Communications systems use the ionised trails of meteors to propagate radio signals. The trails form as the meteors ablate while entering the Earth's atmosphere in the region between 80 km and 120 km altitude. The ionisation allows the refraction of radio signals back to Earth. The height of these trails allows communications up to 2000 km [15]. Meteor Burst communications have been investigated previously by DSTO [16][17]. The physics of the phenomenon do not provide a true continuously 'reflective'[13] medium, though statistically it could be considered such. To use meteor trails the signals are either transmitted in bursts as suitable trails appear or continuously with the acceptance of the loss of packets. Interest in the use of meteor burst communications in the open literature has been on the wane since the early 1990s. While the literature does not state why it has not been taken up by the military, applicability to communications in which packet loss is acceptable is an area worthy of investigation.

4.3 Atmospheric Scattering

Atmospheric scattering describes the use of that component of an incident wave that reflects back to Earth off turbulence and/or reflective particles in the atmosphere.

4.3.1 Ionospheric Scatter.

Ionospheric scatter uses the scattering of signals in the ionosphere at frequencies up to 100 MHz with hops reaching some thousands of kilometres. The bandwidth (and hence capacity) is limited due to the range of radio frequencies it is applicable to however, it presents potential as a phenomena that could be exploited to provide supplementary communications.

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[13] Reflective is used here in the appearance of the phenomena rather than the actual process of repeated refraction.

4.3.2 Tropospheric Scatter

Tropospheric scatter is used in the frequency range 300 MHz to 9 GHz with a range of from 100 km to 1000 km though the normal range is from 150 km to 400 km[19]. It experiences high losses and much multipath, hence systems need: high power, large dishes and often multiple dishes (for space diversity) to reduce the fading effects of multipath. The high carrier frequency allows for moderate capacity and typical systems offer rates of 512 kbps to 2 Mbps. This is a well-known extended range technology, in use in other armies but one that the Australian Army has not employed for a generation.

5. Intermediary Device Techniques

To provide range extension between two nodes an intermediary device is often positioned such that it can successfully communicate with end terminals to relay transmissions between them.

In this section the techniques associated with such intermediary devices are discussed under two broad categories. These are of relay through devices that are peers with the communicating nodes[14], referred to as peer relay, and relay through devices that are not peers with the communicating nodes, referred to as non-peer relay[15]. The section ends with discussion of some implementations of these two categories.

5.1 Peer Relay

The Army currently has procedural mechanisms for the manual relay of messages when stations lose direct connectivity. More sophisticated automated versions of this mechanism are fielded with other armies and some are based on the user nodes creating an ad hoc or self-organising network[16]. Communications between nodes can occur directly or via automatic relaying through other members of the network. Such an approach does not fundamentally provide any extension to the range capabilities of an individual node and relies on an obliging geographic laydown of nodes to provide the required connectivity and range extension/geographic network coverage.

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[14] Two nodes are peers when they have equivalent capabilities. They are not peers if they do not have equivalent capabilities.

[15] In the discussion in this section the concepts of simple relay and switched relay are discussed under non-peer relay. This division reflects the current military use of the available technology. It is acknowledged that, for example, if all nodes have the equivalent switching capability then by the definition of peer they would be discussed under the title of peer relay.

[16] For example the US Land Warrior System and the Enhance Position Locating and Reporting System (EPLRS).

5.2 Non-Peer Relay

5.2.1 Simple Relay

A simple relay device simply re-transmits a received signal. The complexity of the device depends on the point in the signal chain where re-transmission is occurring. Thus the simplest systems would see the received radio frequency continuously received and re-transmitted on another frequency. More complex variations would demodulate and regenerate the signal. Regardless, simple relay systems tend to offer a flexible relay that can accommodate developments in end terminal configuration.

5.2.2 Switching Relay

At the cost of increased complexity, switching (or processing) relays bring greater capability over simple 'bent pipe' relays. The position of the relay still provides for the range extension or obstacle avoidance but processing on board the relay allows for more intelligent relaying. For instance, the relay can process user signalling or packet headers to relay the communication to specific recipients.

5.2.3 Tiered Architecture

Once processing is installed in the relay, there is scope to create a tiered architecture where multiple relays, each with their own geographic coverage, can interconnect to create a single virtual relay. This offers greater range extension with no additional complexity in the end terminal.

5.3 Implementations

5.3.1 Re-transmission

Re-transmission is a conventional CNR implementation of a non-peer simple relay. Typically two transceivers, each tuned to an individually all-informed net, are audio interconnected so that any transmission on one net is automatically transmitted on the other. This is a relatively straightforward means of extending the coverage of CNR, but suffers when dealing with a complex topology. The concept assumes that each net is all-informed. If there is significant fragmentation of the net then several re-transmission stations would be required - this is difficult to co-ordinate and potentially expensive in frequencies.

5.3.2 Two Frequency Simplex Relay

An alternative to SCR re-transmission that is used in commercial nets employs two frequency simplex. All stations transmit on one common frequency but receive on a different common frequency. A well-sited (non-peer) relay station has a receiver and a transmitter operating in the inverse frequency plan of the end user terminals. Provided all user nodes can link to the relay, then all informed operation is achieved, regardless of the ability of nodes to directly connect to other nodes[17]. The two frequency simplex relay is well suited to complex terrain. In very complex situations, multiple relays and a possibly a switching capability may be required creating a second tier interconnecting the relays. The approach is fundamentally a hub-spoke system and is reliant on the operation of the relay (hub) - stations typically do not communicate directly. A sophisticated version of this concept is encompassed in civilian Trunk Mobile Radio systems such as those using the TETRA standard. Other armies have deployed such systems, for instance NATO forces in Kosovo.

5.3.3 Cellular Systems

Cellular systems and the military equivalents (Single Channel Radio Access and arguably also Combat Net Radio Interface) can be considered to be a two tiered switching relay. They offer access into the trunk system and hence range extension. Again, such systems are well understood and employed in some armies.

6. Intermediary Device Platforms

In this section we discuss the platforms that can be used to house the range extension technologies and touch on the limitations they impose. We have already noted that to provide range extension between two nodes an intermediary device must communicate with end terminals to relay between them. Increasing the height of the intermediary relay/re-transmission nodes while retaining line of sight to each of the terminal nodes, increases the range of tactical communications. In terrestrial systems this has been reflected by the tendency to place range extension platforms on high features to obtain maximum flexibility. (An alternate though more restrictive approach is to site the systems at valley junctions.) With non-terrestrial systems literally the sky is the limit - however as the elevation of the platform increases, so too does the time delay (as a signal completes the up-down path) and typically also the system cost. The distinction between the platforms is whether or not they are on the surface of the Earth and discussion is under these two categories. The technical challenge becomes the engineering compromise between the design of the platform and that of the payload in providing the range extension and communications services sought.

6.1 Terrestrial Based Systems

With a terrestrial platform for the relay, the same constraints on the range between nodes apply to the range from user nodes to relay. Some planning and engineering effort is thus required in determining the location of the relay(s) to provide the requisite geographic service area. Civilian systems rely on relatively high capacity/short range links[18] from the

[17] A simple relay will provide all-informed distribution of the communication. Concepts such as closed user groups sharing a common channel would require a switching relay.
[18] Examples are Bluetooth, IEEE 802.11 wireless LAN and cellular phone link.

user into relay/access sites. The relay sites are interconnected and networked to form a core infrastructure typically interconnected via fibre optic. Well engineered geographic coverage to the mobile users is limited only by the economics of return on investment.

In dispersed and highly mobile operations terrestrial range extension equipment can be of a temporary, mobile nature or more permanent, fixed equipments. Fixed assets have a value beyond the immediate needs of the combat or war and assist the post war reconstruction phase by either forming the basis of a civil system or providing a service to a minimal level until the civil system can be brought into service. However, the need to protect them, and any associated wired/cable communications links, during construction and while hostilities continue is a significant disadvantage as well as their inherent inflexibility. Mobile systems/equipments offer an inherent flexibility in their deployment and redeployment. Mobile terrestrial platforms are affected by path loss due terrain and vegetation factors associated with their low altitude. Network planning will call for omniscient/prescient system deployment, or (more likely) an expensive provision of area coverage. Moreover, the most appropriate sites may be tactically unsound or inaccessible to friendly forces. Even those accessible to the friendly communication units will be subject to enemy intervention and this will dissipate combat troops for protection.

6.2 Non-Terrestrial Based Systems

The coverage on the Earth's surface from an elevated platform depends on the platform altitude, the angle of the horizon above horizontal in the direction of the platform and the radius of the Earth. Figure 2 shows the maximum diameter (along the Earth surface) of the line-of sight (LOS) coverage area for station altitudes from 0.5km up to the geostationary satellite orbit. Terrain and buildings will mean that horizon angles up to 45° to the horizontal may be encountered reducing the theoretical (smooth Earth) coverage.

An attraction of non-terrestrial systems is that they seem not to require physical relay assets in the battlespace that would draw combat forces away from offensive manoeuvre to defend them. Some non-terrestrial systems may be able to operate from a sanctuary battlespace, obviating the requirement for any defence. Nevertheless, the platform may yet be vulnerable to enemy interdiction in the area of operations. The detectability and vulnerability of airborne relay remains a subject of investigations.

A difficulty of the non-terrestrial based systems is the accuracy to which they can maintain a position in three dimensions. The degree of their movement away from the designated point, combined with the radio frequency in which they operate, may necessitate sophisticated tracking technology by the user node equipment[19]. Operating without this tracking antenna may lead to an associated loss of quality of service in areas such as throughput. The challenge of non-terrestrial systems is to maximise payload performance

[19] A method of overcoming the need for precise maintenance on station and orientation of the non-terrestrial based system is the use of omni-directional antennae on the system. However, to maintain high data rates directional antennae are required. The trade off between the station keeping requirements and the acceptable data rate available is an operational decision.

and minimise the size of the relay platform. Further discussion of non-terrestrial systems will be under the general classifications of atmospheric systems and space systems.

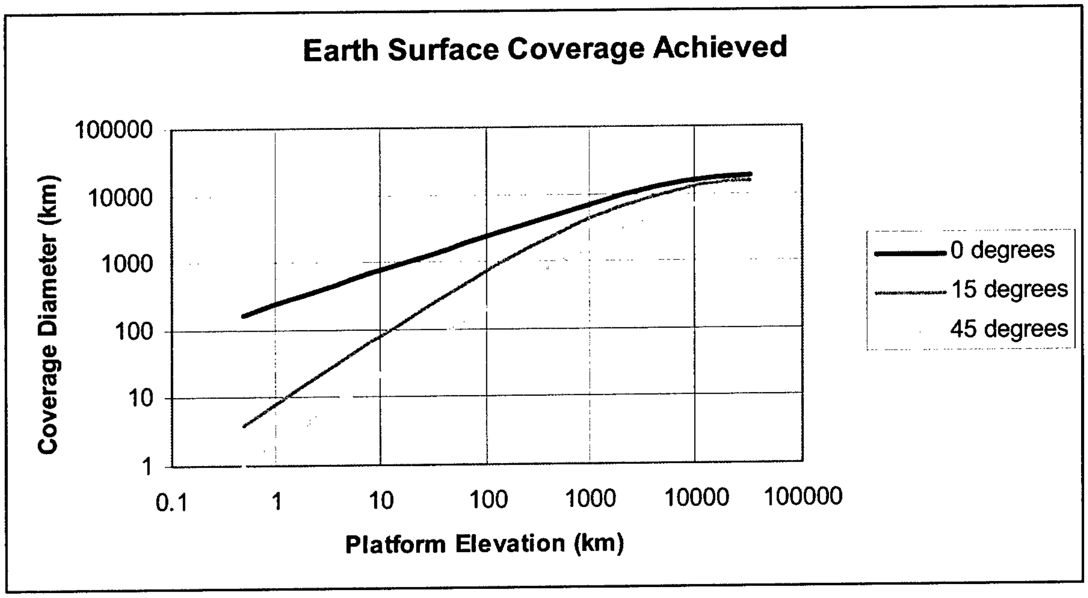

Figure 2: LOS distance coverage range for altitudes 0.5 km to 33,000 km (note logarithmic scales on both axes).[20]

6.2.1 Atmospheric Systems

In their work on a communications architecture for the land battlespace, Ryan and Frater [19] observed that rather than using communications satellites, communications ranges can be extended by communicating through airborne platforms such as aircraft, uninhabited airborne vehicle (UAV) or tethered/un-tethered aerostat. This constituted the tactical airborne sub system in the land battlespace communications system. An advantage of their use was seen to be that the platform can be owned by the tactical commander and is therefore able to be included in the minimum integral communications system.

The use of elevated platforms to provide such range extension brings a new set of problems or constraints on the communications system that need to be considered to determine if and how such extension can be an advantage (for instance see [21]). An issue that occurs in the tactical arena is that of vulnerability. The best performance is obtained from a relay platform that is stationary. However, an atmospheric platform that is stationary is also vulnerable to physical destructive measures and/or narrow beam electronic attack. Thus while an atmospheric platform may not require troops to provide a

[20] Calculations are based on the mean Earth radius of 6,371 km and using the trigonometric Sine Rule.

secure perimeter at its point of operation its physical security can be compromised in other ways.

For convenience we have used the general classifications of heavier and lighter than air as the structure of our discussion atmospheric platforms. Equally valid is the use of the division between manned and unmanned aerial platforms.

6.2.1.1 Heavier Than Air Platforms

We use the description of heavier than air platforms in the conventional sense to describe those platforms that use powered flight to stay airborne. It is reasonable to state that whatever is envisaged as the communications payload there is a platform available that can carry it. The key limitations are the costs of the platform and these are not detailed in this discussion.

Aerial re-transmission using manned flights was practised by Australian forces, using the Pilatus Porter light aircraft, during the Vietnam War. Similarly the use of airborne command and control aircraft by the United States forces and the emergence of the Air-Warfare Controller indicate the capabilities in this area. These systems require service personnel to fly them and maintain them, a base area to operate from and a degree of protection for the base area. In the Australian context the effort has been to use as light an aircraft as possible for this role. Problems normally associated with manned flight are the minimum size of the aircraft due to the presence of flight crew, threat to human life by the requirement to 'stay on station' and the associated costs of spare crew. The advantage of manned systems is their inherent flexibility and hence survivability plus that their size is limited only by aircraft building technology.

The use of UAVs allows constraints dictated by the flight crew component of manned flight to be removed. Thus smaller aircraft sizes, potentially much higher elevations and greater time on station are possible. However, there is a multitude of issues to be considered in the deployment of UAVs and the wide range of vehicles required to support the various payloads and flight profiles. The selection of a platform and payload is not a trivial exercise. To achieve an acceptable solution the selection process involves the enunciation of the requirements for the performance of the system including:

- acceptable upper and lower limits of the height of operation,
- the identification of the technological factors to be considered,
- financial limitations,
- the optimisation process of balancing these considerations and the iterative process of modifying the considerations, and
- the bounds on the considerations.

These aspects are to be explored in a detailed report on UAVs in preparation in a separate task within Information Networks Division DSTO.

6.2.1.2 *Lighter than Air Platforms*[21]

We consider lighter than air platforms in the traditional sense of balloons, dirigibles and like items. In this discussion we consider unmanned lighter than air platforms only. Lighter than air platforms have been used for military purposes for two centuries. Due to the difficulty of control and limited lifespan, aeroplanes, UAVs and satellites have gradually replaced them. For temporary communications over limited distances, the low cost and high altitude still make them feasible choices. The use of balloons is a subject of study under Task JTW 02/099 - Application Performance Testbed for ADF Communications. This activity includes trials of balloons as a range extension method for ship to helicopter communications.

There are several significant constraints on the employment of lighter than air platforms:

- They have difficulty staying on station due to wind drift[22], particularly untethered platforms, and manoeuvre sluggishly. Station-keeping technology adds a payload cost (and hence reduced ceiling) and possibly a manpower cost. Without station keeping technology, continuous communications cover is provided by the scheduled release of new balloons.
- Security issues arise with the security of the communications payload of the platform once it moves off station.
- Air safety and air traffic control are important issues.

ITU has agreed to stratospheric platforms (including aerostats) employing 3G CDMA frequencies. Most interest appears to be in less developed countries as a fast way to deploy modern communications services. Most of the active players have been very quiet recently.

Some pertinent aspects of balloon use from DSTO studies to date are:

- A meteorological balloon takes 1.5 to 2 hours to ascend and about 1 hour to descend if a parachute is used.
- A balloon may ascend to 110,000 feet (33.5km) altitude, covering a ground area of up to 820nautical miles (1520km) in diameter.
- A zero pressure plastic balloon may last for hours or days at a high altitude.
- The high altitude and large footprint can overcome a strong wind drift and jet stream during the three hour flight time.
- Altitude depends on payload weight.
- Weight/logistic aspects[23].

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[21] Much of this information was provided by Dr Weimin Zhang of Military Communications Branch DSTO from his unpublished work within Task JTW 02/099

[22] The jet stream is a major component of the wind. It can be as strong as 280km/hr but only occurs at a thin layer of altitude. Wind direction also depends on latitude as well as elevation.

[23] Of significance is the cost of a lighter than air system. Indications to date are that the cost of balloon, helium and transponder would be about $1000. For a non-recoverable deployment of around 10 ten hours this is a cost of $100 per hour. This is trivial compared to the costs per hour of more ambitious systems.

Among the areas requiring investigation for lighter than air platforms are: operational requirement, transponder design, balloon types and properties, launching feasibility, air traffic control regulations and weather statistics. These aspects are to be explored further under current tasks within Information Networks Division DSTO.

6.2.2 Space Based Systems

Space based systems provide the potential to achieve global coverage (with multiple platforms) with the appearance of being invulnerable to physical attack - satisfying the ideal of both criteria. Satellites are very attractive to the warfighter for these reasons. The limiting factor in all considerations of satellites is the trade off between cost and size of the payload to be carried. Satellites can be considered to be independent of the terrestrial terrain though line of sight is required which brings limitations in complex terrain such as cities with high-rise buildings and canyoned/mountainous type country. A single geosynchronous satellite provides coverage up to 1/3 of Earth's surface with three providing global coverage. This enables very long extension to the ranges of terrestrial communications systems. Except for telemetry and tracking control ground stations, as well as (currently) Earth terminals for switching, satellites are independent of extensive ground infra-structure such as is used in terrestrial systems.

Work is being carried out within DSTO to develop secure mechanisms to provide automatic dynamic assignment of the bandwidth, hence capacity, of the satellite transponder. A significant complication of geosynchronous satellites is the latency due to the finite time taken for the signal to transit the communications path. This has a significant effect on performance when applying protocols such as those used on the Internet that have often been optimised for shorter link delays and also affects on capacity management signalling.

The Earth terminal size and suitability for specific range extension applications are driven by factors such as information rate required, satellite orbital height and frequency of operation. This issue has seen extensive investigation in the open literature and consequently is not discussed in this report. In general, range extension via satellite is a well-understood technology with well-understood trade offs between capacity and terminal bulk/mobility.

7. Other Issues

The use of active relays to extend communications coverage introduces a number of other issues discussed here - security, access to shared relay stations, the routing of communications and performance in the face of network dynamics.

7.1 Security Issues

In the situation where non-peer relay stations are deployed several security related issues emerge:

- Since the relay will be sited in a communications advantageous position, it may well be more accessible than user nodes to the enemy for interception and for intrusion/jamming. There is a case therefore that protective measures applied on direct user node to user node communications are even more relevant on networks employing relays.
- Protection from detection and arguably jamming on direct communications is assisted via transmission security (TRANSEC). Relay stations would then require appropriate TRANSEC capabilities with consequent challenges for keying and potential physical compromise. In the case of switching relays, TRANSEC should seek to prevent intruders from accessing and exploiting the protocol transactions at the relay (for instance intruders consuming capacity, perhaps through playing back earlier traffic, and denying legitimate users access).
- Application of cryptographic security to prevent enemy exploitation of intercepted information may create an issue when switching relays are incorporated into the communications system. While access to user traffic is not needed, such relays will require access to relevant signalling or packet headers in order to direct the communications. Some form of communications security will be required at the relay to prevent enemy interception of this traffic direction information with consequent physical security implications to the relay.
- Unattended or unmanned devices, particularly atmospheric devices, have the risk of the loss of any communications security equipment placed on or in them.

7.2 Sharing Relay Resources

Depending on the nature of the relay device, for instance the expense of the relay platform, there may be a cost imperative to share the relay amongst many user nodes. Access to relays is closely related to the general process of accessing the channel and is encompassed in media access control (MAC) protocols. MAC can be generically divided into those with deterministic delay (i.e. guaranteed minimum delays, such as time division multiple access) and non-deterministic schemes (such as carrier sense multiple access). There is a large body of work exploring performance of MAC schemes especially in ad hoc peer relay networks.

A key performance issue is that of fairness of access, or more generally, the provision support to user quality of service expectations especially in the face of dynamic traffic demands. The familiar demand assigned multiple access protocols used by UHF satellite communications falls into this area, as does the DSTO developments titled secure satellite IP network (SSATIN).[24]

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[24] DSTO reports have yet to be developed.

7.3 Routing

In any situation of switching relay, decisions are required in the relay as to where the communications must be sent. This decision making, or perhaps the dissemination of information upon which these decisions are made, is particularly challenging when there is a tiered architecture or peer network involved and the network topology is dynamic. This is an area of on-going investigation and to date there is a spectrum of approaches from reactive (route discovery occurs only when a connection is required) versus proactive (where routes are determined periodically, whether needed or not, and disseminated around the network).

Military applications often call for broadcast (or more generically, multicast) dissemination of information. Routing decisions, especially in dynamic peer networks, can be problematic especially if efficiency is a criterion (i.e. minimising unnecessary relay transmissions). Research in this area continues including examination of approaches that take a probabilistic approach to delivery guarantees.

8. Conclusion

There is no single technology that can act as the panacea for providing the range extension required by the military. Each technology and system that can be used has differing characteristics that provide different advantages and disadvantages. The relative significance and the interaction of each varies with the circumstances of the deployment. In providing range extension, some approaches also give a technological advantage over a technology deficient adversary (for instance perhaps airborne relay) but it remains to be examined how transitory this advantage may be. Some may provide savings in particular areas, but may have excessive indirect costs that cannot be easily identified. Further, some technologies are well known and hence their risk level is well understood, others are less familiar. It is difficult to envisage meaningful cost-benefit metric(s) that will allow a balanced assessment of the various conflicting strengths and weaknesses to identify a single solution.

Overall, it is likely that the communications providing range extension to troops deployed in the field shall continue to be a mix of technologies dictated by finances available. One should not be seduced by the idea that a single solution such as a UAV will meet all needs - for instance urban, jungle, and inside buildings/tunnels/caves environments can provide particular difficulties for elevated systems.

Some technologies and the associated platforms have been investigated in detail by DSTO and the information is either published or yet to be published. These are:

- Use of Balloons
- Use of UAVs

- Use of Satellites
- Use of ducting for range extension

Other areas in which investigation is currently occurring are routing and media access controls.

Topics that should receive further investigation:

- The use of UWB for communications in urban operations/within buildings.
- The use of MIMO within ADF tactical communications.

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19. ABSTRACT

The adoption of the Network Centric Warfare (NCW) philosophy for Land Force operations means that connectivity through networked communications, typically wireless for mobile operations, is of critical importance. The communications range of the radio equipment becomes a constraint in operational concepts and the degree of implementation of NCW. To overcome this range limitation a series of communications techniques covered by the broad title of 'range extension techniques' enable nodes to communicate within the battlespace through intermediary devices or phenomena. This paper seeks to identify and discuss the broad spectrum of tactical communications network range extension approaches and technologies available. As a result Army will be better informed in the development of communications architectures for deployed Land Force communications.

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