A Systems Perspective on Australian Littoral Operations: Issues and Objectives.

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Abstract

The Australian Defence Force is currently refining its amphibious operations capability, particularly with the purchase of the two landing craft HMAS Manoora and HMAS Tobruk. Vital to the success of a typical mission are the communications, sensor, command and control networks are used to coordinate the major ship, aerial and land assets during an operation. In this paper, we review the communications and sensor networks involved in attaining and distributing information during a particular phase of the operation, the *assault phase*. During this phase, tactical wireless communications links are principally used. Upon viewing the current amphibious operations information networks, we argue for increased systems integration, to enhance the warfighters targeting ability during the assault phase, moving from voice directed locally coordinated targeting, to globally coordinated data directed target selection. We model the benefits of communications and sensor integration and the resulting decrease in the timing of command and control decisions. Through a simple simulation of target selection, friendly and enemy forces target one another over a series of engagements. During each round both sides may strike a number of times as is determined by its activity cycle time. Through simulation, we show that, a decrease in the targeting activity cycle time, compared to the enemy, results in a non-linear increase in the probability of winning the resulting war of attrition. We then outline how systems integration may result in distributed rather than centralised target selection, through the application of a leader election algorithm found in the theory of distributed systems. Finally we discuss future technologies to achieve systems integration, those of ad-hoc networks and distributed data fusion architectures.

1. Introduction

As an amphibious operation encompasses both the land, air and sea domains, it is essentially a Joint Operation, involving all three services. The need for a joint approach to an amphibious operation is highlighted by the establishment of the American Marines and the Royal Marines of the United Kingdom. Both organisations are integrated services of the Defence departments of their respective countries. More than any other military operation, an amphibious mission requires the extensive collection of intelligence, both military and environmental, with the close coordination of both physical and information assets essential for the successful completion of a mission.

The phases of an amphibious operation are characterised through the acronym PERMAT implying Planning, Embarkation, Rehearsal, Movement, Assault and Termination. The responsibility of successful execution of these phases is delegated to the Commander of Amphibious Task Force and the Commander of Landing Force, CATF and CLF respectively [Defence, 1998]. These commanders convey orders through all the phases of an amphibious operation, informed by information from various communications, sensor networks and agencies. The planning phase is instigated through a warning order given to the two commanders from higher command. With this warning order, intelligence, such as the clarification of the task/mission, time frames of the task, alternatives to the task, forces available and support operations to aid in the task [Defence, 1998]. Importantly command and control relationships must be supported by an associated communications/sensor infrastructure.

During all stages of an amphibious operation many concurrent decisions must be made, both by CATF and CLF and the network of associated component commanders[1] as is seen in the following figure illustrating command relationships [Defence, 1998].

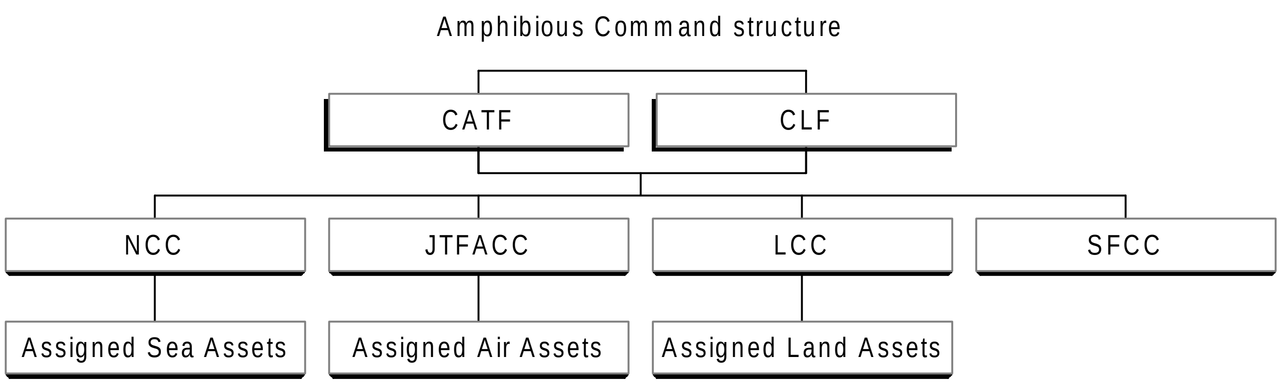

Figure 1: Command relationships in a typical amphibious operation.

In this paper, we focus on the information requirements of a particular phase of the amphibious operation, the assault phase in which land, air and sea assets must communicate and coordinate actions to eliminate enemy defences, both physical (armoured vehicles) and electronic (radar jammers). During the assault phase, the amphibious task force must secure sites such as an helicopter landing zone to carry troops, termed the HLZ, a tactical control centre (TACON) and a centre for the establishment of ground communications, to name a few [Defence, 1998].

Following this Introduction, we outline the Command, Control, Communications, Computing, Intelligence, Surveillance, Reconnaissance and Electronic Warfare (C4ISREW) organisations and structure associated with an amphibious operation. We then argue, that due to the complexity of tasks and the required flexibility of information transfer involved in conducting amphibious operations, the current systems of communication and information transfer must be integrated, to enhance both the situational awareness of commanders and warfighters alike. A simple numerical simulation of target engagement follows, in which we compare outcomes

[1] The component commanders NCC, Naval Component Commander, JTFACC, Joint Task Force Air Component Commander, LCC, Land Component Commander, SFCC, Special Forces Component Commander.

of a war of attrition, where friendly and enemy forces each have different decision times to select a target. We then discuss how the theory of distributed systems may be applied to make non-centralised targeting decisions. Finally, we discuss potential future technologies in the area of mobile communications that may realise the advantages of systems integration.

2. C4ISREW Components in an Amphibious Operation

During the assault phase of an Amphibious operation, the CATF must delegate the coordination of activities, such as landing fire support, landing order and the control of surface ships and helicopters to various organisations/teams under his command. Some of these organisations are transient in nature, as they are established during a particular part of the assault phase, for example when most of the landing assets remain offshore and are disbanded once there is a significant presence of the task force onshore [Defence, 1998].

One example of a transient organisation, altered as the assault phase progresses is the centre for coordination of fire support across the sea, land and air services. This organisation, initially centred offshore is termed the Supporting Arms Coordination Centre (SACC) whose primary aim is to coordinate naval and aerial (aircraft and helicopter) fire support. The SACC is commanded by JTFACC. Once the vehicles and a major communications centre have been established on land, the SACC undergoes a transition, from that of an offshore organisation to an onshore organisation, the Joint Offensive Support Coordination JOSCC centre, under the command of CLF [Defence, 1998].

Apart from the SACC, many other organisations are needed to coordinate the movements of landing vehicles, logistics, aerial and shipping traffic, as is described in the table below (Table 1).

Organisation	Commanded By	Role	Transience
Aerial Reconnaissance Centre (ARC)	JTFACC	SR imagery and other information from recon. aircraft, UAV's etc.	Throughout Amphibious operation
Joint Movement Group (JM Grp)	CATF	Control of landing vehicles during the assault phase	
Electronic Warfare Coordination Cell (EWOC)	J3 of HQAST	Coordination of electronic warfare activities	
Supporting Arms Coordination Centre (SACC)	JTFACC, CLF	Coordination of fire support, from sea and air elements	Exists during the primary phase of an amphibious study
Joint Offensive Support Coordination Centre (JOSCC)	CLF	Coordination of fire support from sea, air and land elements.	Established after landing
Tactical Control Centre (TACON)	CATF, CLF	Coordination of the amphibious operations tactics	
Naval Control Group	CATF	Control of naval	

(NCG)		Traffic	
Helicopter Direction Centre (HDC)	JTFACC	Integrated control of helicopter movement, landings	
Tactical Logistics Group (TLG)	CATF, component commanders	Control of logistics bases, flows of logistics supplies	
Medical centre (CASEVAC)		Coordination of casualty evacuation and treatment	

Table 1: Some of the organisations/groups involved in the command and control of air, sea and land assets during the assault phase of an amphibious operation.

This list of organisations ideally acts in a synchronised manner to coordinate the tactics, traffic and logistics associated with the amphibious operation.

2.1 *The Disunity of Communications, Information and Sensor Systems*

Of greatest importance in the coordination of these organisations is the architecture of the communications/information systems employed throughout the operation. As all the assets forming the amphibious system are mobile, radio communications sub-systems, consisting of networks of "all informed users" at a particular frequency are employed [Frater and Ryan, 1999]. During an amphibious operation, there are many mobile communications systems employed, with at least one for each of the services[2].

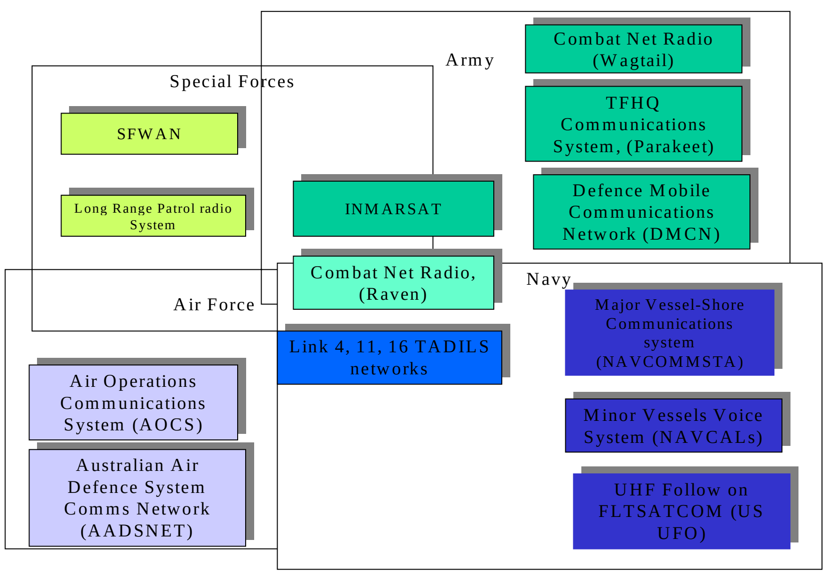

Figure 2: Communications systems involved in an amphibious operation.

An estimate of the total number of communications systems is shown above.

There is a fundamental reason for the large number of communications systems: each system was designed to perform optimally in its own environment. Thus, for long-range radio communications, platforms use bands in the HF part of the spectrum,

[2] We consider the Special Services separately from the Army, Navy and Air Force.

whereas for the data communications of high bandwidth, VHF and UHF spectral occupancy is employed [Frater and Ryan, 1999].

Looking at Figure 2, we see a fundamental drawback of sub-systems adaptation to the particular environment, the disunity of the system as a whole [Ferguson, 2000]. In practise, it is only possible to relay analogue voice across the three communications systems, rather than data packets [Johnston, 1999]. The principal obstacle to the relay of digital data throughout the amphibious tactical domain is twofold in nature. Air and ship assets automatically relay track information through the network of Tactical Data Links, (TADILs), whereas the land assets relay manually entered situation reports to their central information system [Johnston, 1999]. Further to this disunity in reporting situational awareness is the spectral occupancy and multiple access issues of land, air/sea communications, with land combat net radios employing HF, frequency hopping, half duplex communications [Frater and Ryan, 1999]. The tactical data links of ship and aerial assets, TADILs, employ VHF/UHF, frequency hopping, time division multiple access (though HF may be used in Link 11,16) (Defence 2000). If we refer to the OSI model of communications architectures, we have system disunity in three distinct layers of the network [Tanenbaum, 1997]. In the physical layer we have disunity in spectral occupancy, in the multiple access layer disunity occurs in the multiplexing schemes employed and in the application layer, disunity in the representation of information across the services.

Amphibious operations also rely on a complex array of sensors, employed on land/air and sea platforms, to give commanders enhanced situational awareness [Fulghum, 1997]. As with the communications sub-system employed, each sensor sub-system is designed to give maximal performance with respect to the range and environment in which it is deployed. Figure 3 outlines some of the sensor sub-systems employed in an amphibious operation [Cotterill, 2000].

In an amphibious operation the sensor systems must span the air, sea and land environments and in order to achieve a coherent situational awareness picture, sensor systems must be coupled with corresponding communications systems to aid in intelligence analysis and data fusion. We have not outlined the associated sensor networks here. When deploying a sensor network, we must not only consider the appropriate mix of sensor elements to enhance situational awareness, but also the connectivity of the sensor elements.

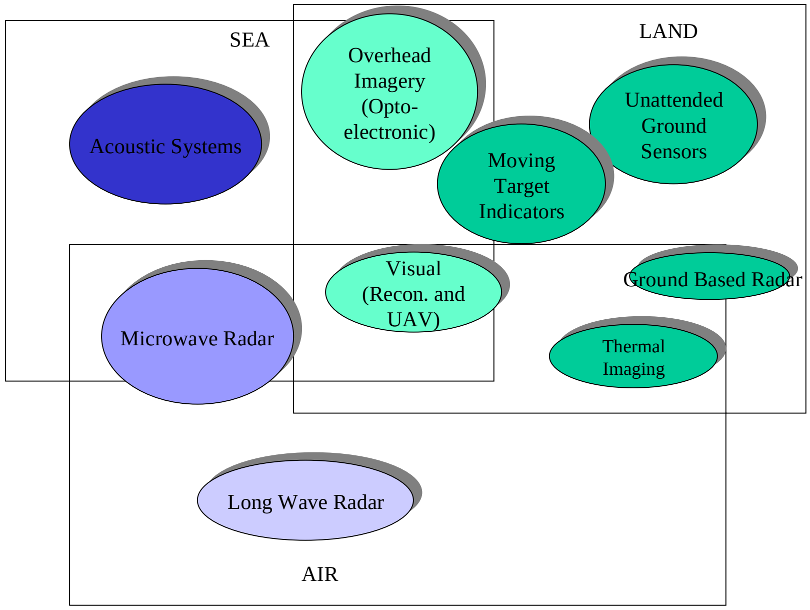

Figure 3: Some of the sensor systems employed in an amphibious operation.

As with the communications systems employed, there are many obstacles towards the integration of sensor sub-systems into one system, in fact they are compounded in sensor systems [Bowman, 1998]. Not only do different sensors use different electromagnetic frequencies according to the environment, resolution and range requirements, but different media are also employed, as is the case of acoustic systems detecting underwater objects and seismic unattended ground sensors. Added to this, we have humans in the data fusion and data interpretation loop. To highlight this, consider the possibility of integrating overhead imagery with information from unattended ground sensors. Both systems use different media for the propagation of sensor information. Overhead imagery relies on electromagnetic waves, emitted or reflected from the objects themselves. Unattended ground sensors rely on seismic waves propagated from the movement of objects within the vicinity of the sensor. There are substantial differences in the command and control infrastructure required in presenting coherent situational awareness pictures from each system.

3. Why Seek Systems Integration?

In this Section, we discuss the advantages and disadvantages of sub-systems integration. As discussed in the previous section, considerable effort would be needed to integrate sub-systems, as each sub-system is designed to work optimally in its own environment. It has become clear however, that systems integration, in terms of communications, increasing the number of interoperable nodes on the network and in terms of sensors, increasing the data fusion capability, has advantages that outweigh the efforts towards systems integration.

The much utilised reason for the advantage of communications systems integration is given by Metcalfe's Law, which states that for a network of N nodes there are N(N-1)/2 possible interactions between network nodes, thus the power of the node increases polynomially. Metcalfe's law is the standard justification for large-scale civilian applications, however we will give another, more military specific reason.

Consider, in an amphibious operation, two networks, a land network and an air/sea network. Both networks can relay voice and data within each network, but can only relay voice across the two networks. In essence this means that if a land node requires fire support from sea/air nodes, it must pass coordinate information via voice. The disadvantages of this system can be seen with the following observations:

- Voice transmission is time costly, compared to the transmission time of one data packet for target coordinates, type,
- Data transmission less costly in terms of bandwidth consumption,
- An additional human in the loop is required to interpret and process voice reports into a coherent situational awareness picture, increasing the time costs in making a targeting decision.

Put simply, network integration implies decreased time and bandwidth, in the broadcast of the situational awareness picture [Cebrowski and Garstka, 1998].

Though the integration of sensor information, data fusion, is more difficult technically, its reason is clear as it provides all decisions makers with a Common Recognised Operating Picture (CROP), improving the synchronisation of decisions. This is not the only reason though, as data fusion may help to increase the probability of target classification and decrease the target position variance.

3.1 *Non-linear Capability Increase with Decreased Decision Cycle Time.*

We have stated that increasing network interconnectivity through the integration of communications systems decreases the time between targeting decisions and requires less bandwidth, reducing friendly radio emissions[3]. Integration of sensor information enables the data fusion process to improve target location and type. How does this improve the warfighting capability of an amphibious force?

The effects of increased systems integration can be studied with a simple executable mathematical model. Five simple parameters characterise this model. There is a blue force with an initial number of "combat elements" N_B and a red force with N_R combat elements. Warfighting here is modelled as a series of "engagements", $r_1, \cdots, r_n$.

[3] The reduction of electromagnetic emissions or EMCON is a vital aspect of electronic warfare associated with Amphibious operations.

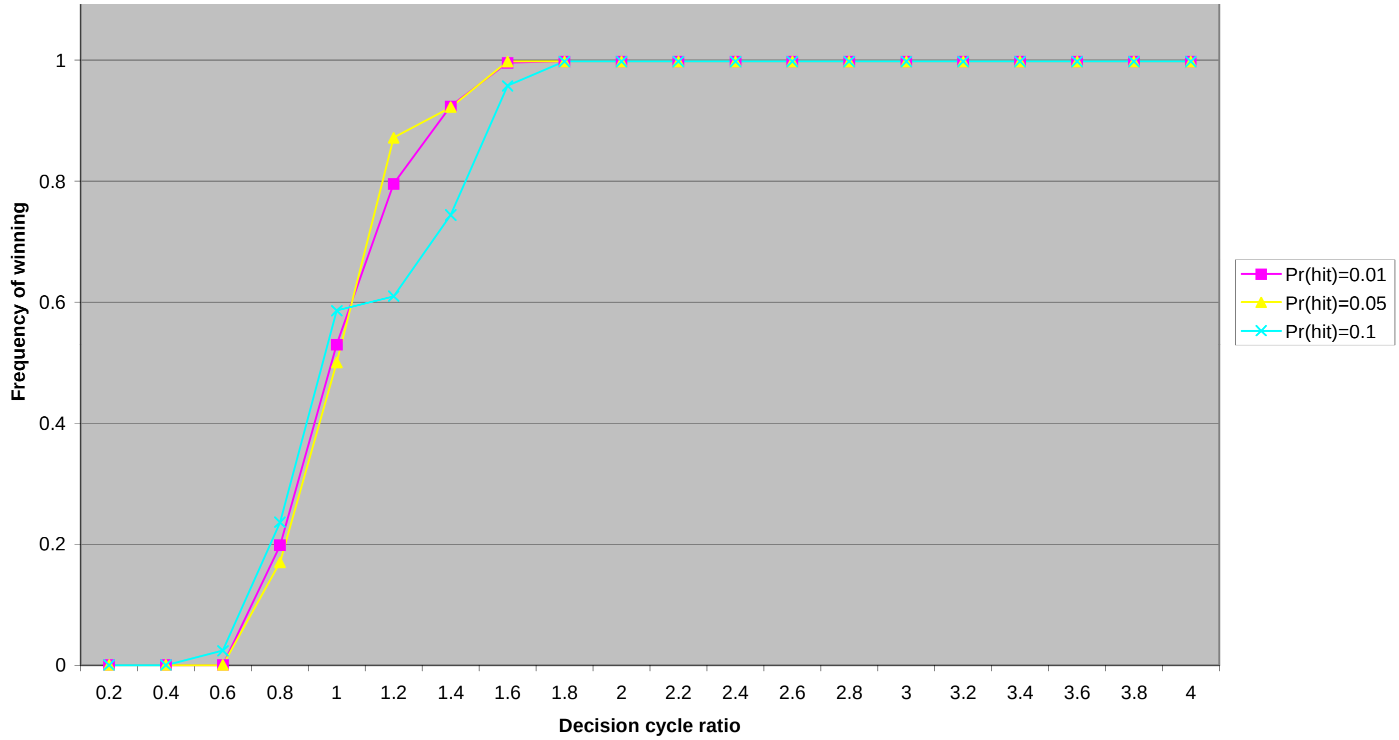

Figure 4: Frequency of blue force wins as a function of the decision cycle ratio. The probability of hitting a target varies from 0.01 to 0.1.

During each alternate engagement, the blue force may target the red force a_{BR} times and the red force may target the blue force in the following engagement a_{RB} times. In essence, the ratio $\left(a_{BR} / a_{RB} \right)$ measures the speed at which the blue force may make decisions over the red force. If this number is large, the blue force may make many targeting decisions compared to each red force targeting decision, thus its "activity cycle" is shorter.

Now suppose a blue combat element targets a red combat element during a particular targeting cycle of a round. Then the blue combat element destroys the red combat element with probability p_{BR}. If a red combat element targets a blue combat element, it is destroyed with probability p_{RB}. Again the ratio $\left(p_{BR} / p_{RB} \right)$ measures the superiority of the blue force to target red combats elements. If this number is large, then the blue force has superior targeting ability, through data fusion and precision weapons.

As the number of rounds proceed, the numbers of both blue and red force combat elements decrease and such a process, in the mathematical literature is called a two-dimensional Markov pure death process, resulting in a war of attrition between the blue and red forces [Ripley, 1987].

3.2 *Results*

As we have discussed the role of systems integration in decreasing the timing of command and control decisions, let us analyse the simulation outcomes, given both the blue and red force have equal targeting ability, $p_{BR} = p_{RB} = \Pr(hit)$ but both have different decision cycles, as measured by the parameters a_{BR} and a_{RB}. In the following set of simulations, both blue and red units have fifty combat elements each, with the number of rounds restricted to twenty.[4] The winner of the game is defined as the force with either the greater number of combat elements after the final engagement has taken place or the force with non-zero combat elements, eliminating the opposing force.

Figure 4 shows the frequency of blue force wins as a function of the decision cycle ratio $\left(a_{BR} / a_{RB} \right)$ for differing targeting probabilities.

Upon inspection of the graph, we may make three intuitive observations. When the decision cycle ratio is small, that is the red force makes targeting decisions at a faster rate than the blue force, then the red force inevitably wins the game. Similarly, when the decision cycle ratio is large the blue force inevitably wins each game.

The most important observation to make is that the frequency of winning the game as a function of the decision cycle ratio is in fact *non-linear*. This implies that for any given increment in the blue force decision cycle speed, there is a *much greater* increase in the frequency of winning the game, no matter what the corresponding targeting probabilities.

This simulation ignores most of the complexities of warfare, in particular assuming that decisions are made over a series of synchronised rounds. However, we may tentatively use these results to argue that an increase in the relative decision cycle speed over the enemy causes a much larger increase in the probability of winning the conflict. In fact, these results also apply to simple games, where red and blue force decisions are made asynchronously [Forthcoming].

3.3 *Distributed Decision Making, A Further Advantage of Integration*

The simple numerical simulation constructed in the previous section highlighted the importance of having a rapid decision cycle and accurate targeting in the C4ISREW set of sensor, communications, decision-maker and shooter networks. Through the integration of sensor and communications networks, one may rapidly transmit information to a joint targeting agency, such as the Supporting Arms Coordination Centre, for the coordination of targeting across land, air and sea platforms.

Command centres, such as the SACC are prevalent across all domains of warfare in the Australian Defence Force. However, these command centres are subject to what is commonly known as surgical strike, with precision guided weapons. Thus centralised command centres, possessing the ability to fuse information and make coordinated decisions are inherently vulnerable [Lambert, 1999].

It is not difficult to see that decision making must move to the distributed domain to increase the survivability of the C4ISREW system. Furthermore, decision making will have to be increasingly automated to improve the speed of the activity cycle

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[4] We have restricted our analysis to only 500 runs for each set of parameters. This was done in order to gain qualitative insights rather than strict statistical results.

[Cebrowski and Garstka, 1998]. How can this be done in practise? Here, we give an outline of how a decision, such as platform to target allocation may be achieved in a distributed fashion.

With an integrated network, all platforms may have information about each of the possible targets to engage. The network of platforms must choose a leader node to engage a particular target. In the theory of distributed algorithms, the choice of a preferred node in the engagement of a particular processor is implemented through a *leader election algorithm* [Lynch, 1996].

Here is a description of the leader election algorithm for a synchronous network, that is a network where nodes communicate to each other over a series of synchronised rounds.[5] Apart from the requirement that the network communicates in a synchronised fashion, we assume that each node knows the *diameter of the network,* that is the maximum distance over all the shortest directed paths between any two nodes of the network [Lynch, 1996]. Each node in the network has a unique identifier or UID. The algorithm simply floods the network with the maximum or best UID. The state of each node, *state(I)* is initially its UID and this changes as other nodes pass their respective UID's to this node. The status of each node is either *unknown, non-leader or leader.* The set of nodes that node *I* can talk to are called its *out-neighbours(I*) and the set of nodes which talk to node *I* are called its *in-neighbours.* Here is the algorithm:

If rounds < diameter then

Send max-UID to all j belonging to out-neighbours

rounds = rounds +1

Let U be the set of uids that arrive from processes belonging to in-neighbours

Max-UID = max({max-UID},U)

If rounds = diameter then

If max-UID = u then status = leader

Else

Status = non-leader.

Put simply, each node compares its current UID with its neighbours UID's, finds the maximum and sends this to other nodes. The node that is the leader is the one that consistently receives its own UID throughout each of the rounds.

The leader election algorithm may be applied to a military tactical shooter network. If we consider each node's UID (the node in this case is a land, air or sea platform) to be some criterion upon which we calculate the probability of successfully engaging a target, then the leader election algorithm will find the best platform to engage the target. Such a criterion may include the distance to the target, the weapon of that platform, the number of missiles left to name a few.

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[5] A round is completed when each node in the network has both exchanged and received a message from its neighbouring nodes.

The leader election algorithm provides an example of a distributed algorithm that may be adapted to allocate a platform weapon to a particular target. We may extend this algorithm to elect multiple leaders, with the military application of selecting multiple platforms to engage multiple targets [Lynch, 1996]. In general, such algorithms are called *network consensus algorithms* which can be constructed to work when there are link failures or so called *Byzantine failures*, that is, failures of the nodes themselves to do the correct comparison of incoming messages [Lynch, 1996].

4. **Discussion and Conclusions**

In this section, we re-address some of the issues of this paper and discuss possible future technologies to implement, what is currently called network-enabled warfare, in an amphibious context, with the ADF.

Let us first turn our attention to the communication systems involved in an amphibious operation. We highlighted the disunity of current communications systems. Each service has its own particular communication system that is adapted to its own particular operating environment making system integration difficult. There are three potential technical solutions to unify communication systems required to provide quality of service in a mobile, potentially hostile environment.

The first technical solution is to place reliance of the transmission of bandwidth to a satellite communications based infrastructure. There are obvious advantages to this, such as the transmission of high bandwidth services to wide ranging areas. TADILs may also be implemented with a satellite communications infrastructure, through a satellite modified Link-16 termed S-TADIL-J [Defence, 2000]. We cannot guarantee, however, that a particular operation conducted by the ADF will be within the available footprint of the communications satellite. Furthermore, it is extremely expensive to launch satellites.

To overcome these problems, many authors have suggested the use of Uninhibited Aerial Vehicles (UAVs), not only as surveillance assets, but also as communications relays [Frater and Ryan, 1999]. Prior to the H-hour of an amphibious operation, a high altitude UAV may be deployed to relay information across all tactical platforms, replacing the need for the availability of a satellite communications “footprint” [Frater and Ryan, 1999]. The use of UAV’s as communications relay is gaining acceptance, particularly as a potential system for a unified land communications systems architecture [Rankin, 1999].

The reliance on UAVs as a communications platform, though attractive, has one crucial drawback. A UAV is vulnerable to attack from an anti-radiation missile [Defence, 2000]. One way to overcome this problem is to make the UAV expendable. Such an example is a balloon borne communications relay for ADF helicopters. Balloons are inexpensive and if destroyed, another relay may be deployed [Zhang, 1999].

A third technical solution to the integration of cross service communications systems comes from a fundamental observation of the network structure of the mobile units within the ADF today. All mobile networks are of a spoke and hub topology, where the satellites, UAVs or communications base-stations form the communications hubs and the spokes the outlying platforms themselves. There is no routing capability amongst the platforms themselves. Though such a spoke hub network topology is common in such industries associated with logistics and air-travel, it is the incorporation of enhanced routing capabilities within the distributed communications network called the Internet that has brought about its flexibility and scalability [Peterson and Davie, 1996].

ADF mobile platforms that have receive/transmit *and routing* capabilities may form the future integrated communications infrastructure. Such networks, termed *ad-hoc* networks and the information routing strategies they use, are currently under study in the civilian domain [Royer and Toh, 1999]. Because of their intrinsic survivability, the ADF and in particular DSTO should seriously consider a study of the military applications of ad-hoc networks.

Having discussed the integration of communications systems, we now to turn sensor networks. Two questions must be answered when considering the integration of sensor information. At what level do we require sensor integration, the tactical, operational or strategic levels? What situational awareness picture is required, for each level of command in an amphibious operation?

In the author's opinion, the situational awareness picture, constructed through integrated sensor information is at present only applicable to operational level planning. The question of whether a custom situational awareness picture is required at the tactical level must be subject of military experimentation. We will discuss situational awareness pictures, at the individual soldier level and the tactical commander level [Pew and Mavor, 1998].

The United States Army is currently experimenting with giving individual soldiers advanced situational awareness capabilities [Carroll, 1999]. Soldiers, with head mounted displays will receive real time information on enemy locations, apparently giving a ten minute warning of incoming treats. With laser sights, soldiers can relay targeting information to a JSTARS aircraft, to call in mortar fire and identify friend from foe [Carroll, 1999].

This project, termed Force XXI, represents the extreme end of the philosophy of network enabled warfare. Though the promises of individual soldier real time situational awareness displays show great potential, there are a number of fundamental drawbacks in applicability within the ADF. First, there may be a potential over-reliance on the equipment, leaving forces exposed with equipment failures. Second, the equipment is bound to be heavy. Finally, Force XXI equipment will be expensive, with modifications required in aerial assets to support the information flows.

At the command level, there are many options for in the relay of information to decision makers. Within an amphibious region of operations we have a variety of assets that may be grouped in a number of ways. For example, we may group the landing force into section, company, platoon, up to brigade units [Defence, 1998]. With a particular representation chosen for each combat element, we must choose a way of representing that combat elements state, such as position, past or projected position, fuel and lubricant supplies, number of casualties etc. In essence, there are many options for the representation of information to an amphibious commander. Each option requires a particular set of sensor networks and data fusion architectures. Which representation is most important is the subject of investigation [Pew and Mavor, 1998].

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