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Position Reporting in a Constrained Communications Capacity Environment

R.E. Dickinson and W.D. Blair

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ABSTRACT

A fundamental of Network Centric Warfare is situational awareness. Situational awareness includes knowledge of own force combat effectiveness, positions and intentions. The method of disseminating the knowledge of own force positions and how current that information is are the subject of much discussion. The universal distribution of perfectly synchronised position information over the land battlespace is likely to be impossible due to constraints in communications capacity. This report considers the trade-offs between complexity of processing, communications capacity and accuracy of position information. It draws on modelling efforts within Information Networks Division that may assist in considerations of a trade-off study.

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Executive Summary

Network Centric Warfare (NCW) requires the commander to have an appropriate level of situational awareness of forces, both those of friendly forces and those of the enemy, that may affect his battlespace. Part of this situational awareness of own forces is the knowledge of their positions. With frequent enough reporting of positions, modern computing technology provides the capability of processing and presenting the information at the relevant locations as a visual presentation that appears as continuous movement. In the modern battlespace, containing highly mobile elements, this information is passed through the network by wireless communications. The increase of reporting capability driven by the ability to present the information requires a greater volume of information being exchanged across the wireless network. The major limiting factors in wireless networks are the capacity of the links between the nodes in the communications network and the management overheads of the communications protocols. These physical constraints affect the amount of information that can be passed on the network. The universal distribution of perfectly synchronised position information throughout the land battlespace is likely to be impossible due to these constraints.

There is emerging interest in the merits of different position reporting doctrines. In terms of capacity there exist tensions between the sophistication of the doctrine (the processing at the nodes), the accuracy of the position knowledge base of the entities and the consequent demands upon the communications network. This report considers the trade-offs between complexity of processing, communications capacity and accuracy of position information.

This paper draws on work done in studies of *ad hoc* communications networks including investigations into the structure of a possible data distribution network in support of tactical Australian military forces. It investigates those aspects that can be controlled by the user to reduce the demand on the communications network. The inevitable conclusion is that while the ideal may be for commanders at any level to be able to zoom in to detail anywhere in the battlespace plus have sensor-controller-shooter communications links of adequate capacity, there are laws of physics and technological constraints that preclude this. Position reporting doctrines need to be carefully considered in the context of who needs to know the information and how often does it need to be updated. Models that can assist in providing quantitative and qualitative analysis are introduced in this paper and continue to be refined.

These and future investigations of the use of various communications architectures to provide maximum capacity assist the development of warfighting philosophies by providing informed knowledge of the capability of the supporting communications system. This will help ensure the warfighting philosophies are applicable in the expected communications environment.

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1. Introduction

1.1 Background

Network Centric Warfare (NCW) requires the commander to have an appropriate level of situational awareness of both friendly and enemy forces that may affect the battlespace. Part of situational awareness of own forces is the knowledge of their positions provided by location reporting. In the modern battlespace containing highly mobile elements this information is passed by wireless communications. The major limiting factor in wireless networks is the capacity of the links between the nodes in the communications network. These physical constraints affect the amount of information that can be passed on the network.

The second Gulf War (2003) demonstrated the usefulness of collecting and disseminating real time or near real time position location information throughout the battlespace by using satellites to provide the connectivity for the Force XXI Battle Command (FBCB2) blue forces tracking system [1]. Informal reports indicate that in this war the deployed US military forces were passing 3 Giga bits per second (Gbps) of data across the total of their communications networks [2]. These figures reflect the ability of modern communications technology, however such capability comes at a dollar cost. Moreover, if the complete reporting of each element in the battlespace to every other element in the battlespace is expected, then we argue here that the volume of data and speed of passage required shall exceed the capability of foreseeable communications systems and technology. This paper is written in the context of an Australian constrained capacity environment in which network capacities of this order are not possible.

There is emerging interest from Land Warfare Development Centre and others into the merits of different position reporting doctrine. The authors believe such studies should explore the tensions between the sophistication of the doctrine (the processing at the nodes), the accuracy of the position knowledge base of the entities and the consequent demands upon the network in terms of capacity. The studies thus entail a multi-disciplinary effort encompassing operators, operational analysis as well as communications expertise.

This paper draws on work done in studies of *ad hoc* communications networks and investigations into the structure of a possible data distribution network in support of tactical Australian military forces. In these studies variations on the reporting of position data as it affects the traffic load on the network were examined. It is offered as a contribution to the position reporting consideration under DSTO Task ARM 02/301 Deliverable 1.1 and in support of DSTO Task ARM 03/053.

1.2 Purpose

This paper discusses the issues raised with position reporting in a constrained capacity wireless communications environment. While concepts are applicable across all environments, the considerations are based on the communications environment provided by the introduction of Joint Project 2072 – Battlespace Communications System Land/Air but not specifically including communications introduced under projects such as Land 125 – The Soldier as a Combat System. In particular, the paper will:

- articulate our own understanding that some entities might require greater fidelity of position information than others;
- describe the challenge/benefit of organisational/hierarchical netted communications operation;
- describe the option for flat communications infrastructure to overcome organisational constraints;
- relay some of our observations, about communications implications of position reporting, published in the 2002 Land Warfare Conference; and
- propose some useful metrics that might be extractable from our network modelling that illuminate position reporting discussions.

2. Position Reporting Demands

The amount of position reporting data to be moved across the communications network is fundamentally[1] dictated by:

- the number of nodes on which data is to be reported,
- the size of the data packets of the reports, and
- the frequency with which the reports need to be made.

Consider the data transfer requirement for all elements (combat, combat support and combat services support) of a brigade sized Task Force.

- Allow this Task Force to have 5000 soldiers, 3500 vehicles, deploy 6000 sensors, 1000 collective nodes[2] and 1000 items of equipment other than sensors and vehicles that it needs to track. This gives a total of 16500 nodes.
- Consider a reporting frequency such that it provides a continuous image to the viewer of a graphic display (approximately 31 ms or 32 times per sec)[3].
- To report a location takes up 240 bits[4].

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[1] Depending on network topologies, other factors might include the number of nodes to which data is to be sent and the possible need to retransmit the reports in a relay function.

[2] A collective node could be that designating a headquarters/command element (TFHQ down to Sect HQ) but excludes organizational collectives that are represented by an area on the map (Bn/Coy/pl).

[3] [3] Box 1 p3

This results in a total input to the communications network of 126 Mbps of raw information. Scaling to match the size of the US forces in the Second Gulf War of approximately 20 Brigade[5] equivalent organisations gives a minimum requirement for comparison of 2.53 Gbps of raw data. Without the overheads that are discussed in Section 3.1 this would constitute two thirds of the capacity that was available. This is own force position reporting only. Facing a similarly sized or larger force whose positions are also being reported as operational intelligence and including the possible need to monitor non-combatant movements increases the demand beyond this figure. Added to this positional reporting demand are operational and administrative traffic. The communications capacity required to move this amount of data exceeded the ability of the United States forces with the most advanced military communications currently in existence. Consequently, 'continuous' position reporting of all force elements to all other force elements is not currently feasible and at least one of the three variables of demand needs to be reduced.

3. The Challenge

The challenges for the current Australian land tactical communications/information system can be summarised as an amalgam of: "not enough wireless link capacity, not enough connectivity and current technology not data focussed".

3.1 Wireless Link Capacity

Wide area communications in the tactical arena is almost exclusively via wireless means. In such cases, communications capacity is constrained by a number of mechanisms, but the most fundamental is limitation in radio bandwidth. The absolute limit to capacity (bit rate) within a given emitted bandwidth can be calculated via a formula developed by Claude Shannon in the late 1940s. It is sufficient to say here that capacity is directly related to emitted bandwidth (ie increased bandwidth allows for greater capacity) and signal to noise ratio (ie improved signal quality allows for greater capacity). Unfortunately both radio bandwidth and signal quality are generally constrained in the land tactical environment. Consequently, the information carrying capacity of these tactical channels is also constrained.

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[4] For the purpose of our numerical analyses in our modelling, basic situational awareness information is assumed to be carried in a 240 bit packet of information. This is based on the message payload of an Australian Army Battlespace Command Support System location report and is consistent with Nilsson, Hansson and Sterner [4].

[5] This detail is deliberately sourced from publicly available information through [5]. The figure of 20 Brigades is drawn from 18 manoeuvre brigades plus an additional figure for Divisional and Corps troops not included in the manoeuvre Brigade structure. Greater values in the number of brigades or associated nodes per brigade would increase the demand.

The commercial world has sought to increase capacity by shifting emitters to ever higher frequency bands for the carrier frequency. These higher frequency carriers allow for greater assigned bandwidth and hence opportunities for higher link capacities. Within the tactical environment, there is a significant disincentive for striving for these higher frequency bands. The higher frequency bands suffer increased propagation path loss so reduce the range over which the link can be sustained unless directional and or elevated antennas are employed[6]. As the carrier wave frequency increases the propagation characteristics behave more like visible light limiting the range of radios to optical line of sight.

In relation to signal quality, the military arena suffers through a need to operate within a tactical regime. This leads one to employ small, low visibility antennas - often lower gain omnidirectional to avoid set up delays and minimize siting planning - sited in tactically appropriate locations rather than on high features. Much of the improvements in mobile commercial wireless services have relied on the greater signal quality that can be achieved via a hub-spoke arrangement where small mobiles link to powerful, well sited (on high features) base stations.

A further impost on capacity is the effects of the communications protocols employed on the communications system. Such imposts reduce the user's share of the link capacity via:

- data overheads (such as packet headers) required for protocol layer interactions;
- traffic overheads from non-user traffic such as network management traffic;
- wasted wireless time coming from unintended simultaneous transmissions; and
- protocol interaction effects such as unnecessary data retransmission and unused time on the channel.

3.2 Connectivity

Whereas air and to some extent maritime operations are conducted with radio visibility between the limited number of nodes, the land domain is more complex. Combat power in the land domain is achieved with a much larger number of nodes and will often occur over uneven terrain. The effect of terrain is mostly evidenced in the inability of some nodes to link with others. Our analysis of Army Experimental Framework data has shown frequent periods when nodes are disconnected from any other nodes; also segmentation of a brigade sized group such that battlegroups were isolated from one another.

Node connectivity is further influenced by doctrinally driven factors. Conventional communications systems are arranged into networks following designs that may not provide rich connectivity that would be best suited for position reporting. Most of the networks follow the organisational hierarchy - some operating as a hierarchy of sub-networks (eg combat net radio) or dedicated links.

[6] Inappropriate for broadcast services and inducing node setup delays.

- There is an advantage if traffic is localised to a "community of interest" in developing sub-networks but this imposes relay responsibility for all-informed traffic that may be required for position reporting.
- Dedicated links provide some guarantees of service, but lose their advantage when broadcasting information.

At Appendix A is a discussion on different network structures and the implications to broadcast traffic such as position reporting.

3.3 Data Networks

The technology supporting the current suite of communications systems has been developed in support of voice applications. While recently fielded systems are 'digital' this infers digitised voice and does not necessarily mean that data is carried efficiently. The carriage of data services over a voice infrastructure can be sub-optimal, for instance:

- Cryptographic synchronisation on voice oriented combat net radio is well suited to relatively long voice connections, but extremely inefficient for short data packet transmissions.
- Voice services can sustain higher error rate than data. Voice oriented digital radios, in seeking low end to end delay, can therefore operate with lower performance modems. Data services require better error performance from its modem but can sustain longer end to end delay in order to achieve this better performance.
- Constant bit rate channels on trunk telephony systems are poorly suited to the intrinsically variable demand from data services.

The fielding of equipments under JP 2072 is planned to significantly address aspects of these issues.

3.4 Communications Implementations Within an Australian Brigade

Up to the year 2012 communications within an Australian Brigade are expected to be provided under JP 2072 down to platoon level. Project Land 125 is expected to satisfy communications needs for at least below platoon level. The architecture for the Land Battlespace Communications Systems envisages five sub-systems: Combat Radio Sub-System, Tactical Data Distribution Sub-System, Tactical Trunk Sub-System, Tactical Air Sub-System and Local Sub-Systems. The Combat Radio Sub-System includes the current concept of combat net radio providing communications down to platoon/vehicle level and the Land 125 communications at infantry section /personal communications level. Local Sub-systems can be expected to be wired or use other localised high capacity systems and are not discussed in this report. Personal communications systems other than those provided by Land 125 are also not discussed in this report.

3.4.1 Combat Radio Sub-System

3.4.1.1 Combat Net Radio (CNR) Capacities.

CNR is a traditional military communications medium. It employs the principles of peer organisations in the command hierarchy netted under a net control station sited with their superior headquarters. The net is engineered (via retransmission stations if required) ideally to be all informed. The entire system thus comprises a number of nets organised into a hierarchy reflecting the organisational hierarchy supported.

CNR can operate in a number of bands. The key medium is the military VHF band (30 to 88 MHz). Such a channel currently offers in the order of 8 kbps with error protection, however channel access/cryptographic synchronisation and data packet collisions reduce throughput to less than 4 kbps. (We ignore HF for moment as it has an order of magnitude less capacity). Depending on the CNR selected, JP 2072 will see a small improvement in channel capacity to certainly no more than 64 kbps in the best of circumstances. Improved data oriented protocols will mean that effective throughput will be much closer to the channel rate.[7]

If one considers VHF CNR networking in brigade - say 132 VHF nets with average of 7.5 stations per net, this gives a notional total capacity of say 528 kbps (assuming 4 kbps). However, if all messages are to be transmitted/retransmitted on each net then the rate is effectively only a single channel rate ie 4 kbps as at present.

3.4.1.2 Land 125 Communications

Communication systems being investigated under the Land 125, Soldier as a Combat System Project, operate at the highest part of the UHF band. At the platoon level these are intended to be independent, all informed, broadcast networks allowing peer to peer and the automatic relay of communications. The range of these systems could be up to 1.3 km but the normal operating range will be terrain/vegetation dependent. It is expected to be beyond visual distance (ie that distance that would have supported field signals by hand gesture) but within integral weapon support range. Links into the CNR networks are being investigated but remain to be resolved. Channel rates within the networks are of the order 2 Mbps shared by all members of the network with effective throughput dependent on the number and activity of members on the network.

3.4.2 Tactical Data Distribution Sub-system (TDDS)

The land battlespace communications architecture includes a specialist data communications means for mobile users. A mobile *ad hoc* network is a candidate architecture being investigated by DSTO. Such a system is not yet fielded in Australia and

[7] Advanced radios such as produced by Harris Corporation offer adaptive rates with maximum rate in the VHF 25 kHz channel of 64 kbps. "Packet mode" as used by the SINCGARS ASIP radio and standardised under MILSTD 188-220 offer data-optimised cryptographic synchronisation and sophisticated channel access controls to reduce collisions.

is envisaged as a part of Phase 3 of JP 2072. The considerations in this report are based on system performance achieved in US and UK land tactical systems.

Overseas deployments would suggest that a TDDS would be deployed with 2 nets in a brigade each operating at 512 kbps on a channel (total 1024 kbps). Since these implementations are inherently multi-hop networks, this channel rate is subject to interpretation from the penalties of message relay and benefits of frequency re-use, as discussed in Appendix A.

3.4.3 Brigade Trunk Systems

Trunk systems operate on a topology employing an arrangement of point-to-point links. Such a system is not yet fully fielded within Australian brigades but expected in later phases of JP 2072. Deployment is envisaged to link Brigade HQ to each of 4 sub-ordinate units plus logistic support elements and other Brigade Headquarters elements. On the assumption this will be using either a lightweight line of sight radio or satellite radio, one might envisage a dedicated 128 kbps capacity link. This gives a total capacity of 512 kbps.

3.4.4 Tactical Airborne Sub-system

The Tactical Airborne Sub-System is ill defined at this stage but is envisaged as an airborne relay for the other three systems to provide range extension. By reducing terrain effects, higher frequencies might be usable thus offering higher capacity links plus the reduction of interference from noise is likely. These factors will result in greater range and/or capacity on the link.

3.4.5 Total Capacity Available vs Potential Capacity Required

The total aggregated communications capacity within the brigade is around 2 Mbps. This falls far short of the potential requirement as calculated in Section 2. Moreover:

- This ignores voice usage of the network that is not fully defined but likely to be substantial.
- It ignores requirement for relaying from sub-network to sub-network and within sub-networks that is topology and traffic dependent.

4. Remedial Approaches

4.1 Doctrinal Options to Moderate The Communications Load of Position Reporting

This section of the report explores possible approaches to reducing the communications challenge presented by location reporting by exploring different reporting disciplines. The underlying premises of this discussion are:

- that commanders will require information about those nodes that will be in their area of responsibility or soon to enter into their area of responsibility, and
- the principle of sensor to controller to shooter information flow is retained.

The natural desire for the same continuous picture to be available to all is not achievable within tactical communications capacity. Consequently there is the need to reduce the universality and/or accuracy whilst minimising impact on operational situational awareness. Potential approaches are reflected in many current practices that have been developed in manually intense systems operating over low reliability, low capacity but high latency communications links. Some of these are:

- Constant rate of universal reporting but at reduced frequency of update - this has been one of the traditional approaches to dealing with low capacity high latency communications reflecting manually intense reporting systems and leads to a straightforward calculation.
- Reduce the extent of distribution of individual reports - this has been another of the traditional approaches that has been re-inforced by the 'need to know' principle. Generally this has been done and is likely to continue to be done using some organisational basis.
- Aggregation of information by reporting only headquarters in accordance with the 'one up two down principle' and 'forward line of own troops' reporting augmented by the users professional knowledge of the disposition of the associated forces has been another traditional method of reducing the load on the communications systems. These have been traditionally associated with the previous two methods. An expansion of this method of aggregation of position reports through automation and the use of doctrinal rules, eg goose egg for unit position rather than individual entities within unit. While this is not explored in this report, we note that this may present difficulties considering dispersed operation and the detailed knowledge requirements of NCW.
- Variable rate of individual reporting triggered by distance/time of last report threshold being exceeded. Though this is another traditional reporting discipline, the availability of global positioning systems and automated monitoring of progress/time can enable reports to be prepared more frequently without distracting the user from their operational mission.
- Subscription model - subscribe to unit position reporting when the sender or recipient is within the other's sphere of influence.
- Combination of the other approaches above.

Such general approaches may also be applied to automated position reporting. There is a tension between the complexity of reporting rules (and hence processing required at nodes), communications network load and the operational situational awareness held by each node in the force. A consequent trade off is required.

4.2 New Communications Technologies

A report [6] discussing range extension technologies for a tactical network supporting deployed forces on dispersed, littoral, amphibious and urban operations is available. DSTO Military Communications Branch has also been requested to investigate increasing the information throughput of communications systems and enhancing the connectivity between communicating nodes operating in complex terrain and harsh environments. The results of these investigations will be produced in separate reports.

Notwithstanding these future reports, progress in the use of various technologies is indicated within the commercial market today. The commercial push for ubiquitous computing is driving the civil communications technology and design areas to develop practical very high capacity wireless links to support it. Personal communications systems deployed using fourth generation cellular telephone technology[8] also promise much, as does the use of satellite communications in the 2003 Gulf War, theatre broadcast in East Timor, the Joint Tactical Radio System (JTRS) and the Wideband Networking Waveform (WNW).

5. Investigations to Date - Communications Modelling Support to Analysis

To date Information Networks Division work has focussed on employing a dataset from the Army Experiment Headline 2000. The logs record movement of 180 identified nodes operating for a period of 2.5 hours in a brigade operational environment. Positions were automatically recorded every five seconds or so. Digital terrain for the fictitious exercise scenario is available to permit communications link analysis. This dataset offers an opportunity to examine future doctrinal force tactics with human decision makers in the loop.

5.1 Analytical Approach

Analysis has been conducted under DSTO Long Range Research Task 01/090 and the Battlespace Communications Land Task JNT 99/141. The results of this investigation are reported in a recent Land Warfare Conference paper [8]. This used an analytical model of the radio network produced by the Teletraffic Research Centre (TRC) of Adelaide University [9] to examine the traffic oriented metrics of average broadcast traffic, maximum broadcast traffic and hop count. The analysis sought to explore the effect on traffic of three different reporting doctrines:

- The first doctrine is simply for all nodes to periodically broadcast their location to all other nodes.

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[8] A recent RAND report [7] discusses some difficulties associated with the use of 4G terrestrial networks in the mobile battlespace.

- With the second doctrine, locations are sent only when a node has moved beyond a globally defined threshold of distance, or a globally defined period of time has passed since the last report.
- The final doctrine adopts a 'subscription' model and has nodes subscribing to high fidelity picture of those nodes within the range of the subscriber's operational effect - a lower fidelity picture is maintained globally.

The analysis quantitatively shows the network benefits of the more creative doctrines of position reporting. The initial findings showed that significant reductions in network traffic occurred by adopting the second doctrine, but extending to the third doctrine highlighted that further reduction was less significant despite the additional complexity.

The traditional output from network modelling has encompassed metrics known as traffic statistics such as capacity and queue lengths etc. These have provided indicators to the efficiency of the communications networks and are used for network dimensioning; both are of significant import to communications network managers. They are, however, not of direct value to evaluation at military operational effects level. While these metrics remain important to the exploration of position reporting options by evaluating the communications feasibility of the option, additional metrics might be investigated to assist in identifying the interaction between communications capability and operational situational awareness dissemination doctrines.

An extension to the TRC analytical model was explored to visualise the accuracy of friendly position knowledge at a command node of the other nodes in the wargame. The commander's accuracy was depicted via the use of three colours:

- Red icons where the commander's understanding was greater than 1km from reality.
- Yellow icons where the real situation was between 100m and 1km of the commander's understanding.
- Green icons for within 100m.

Figure 1 shows a single frame from an animated visualisation of the wargame. It is in two halves with the left half depicting the picture using hierarchical combat net radio (CNR) networks, whilst the right half depicts that from an *ad hoc* network architecture. The command node is depicted as the white node, approximately in the centre of each frame.

This extension to the analytical model was conducted specifically to explore concepts for performance visualisation. No analytical measures were developed to describe the relative performance of the two approaches.[9] It fundamentally presents node connectivity varying

[9] Note that this extension to the analytical model was known to have limitations. The TRC analytical model was designed to dimension traffic loads and hence was not capacity limited. Consequently, the extension was depicting location reporting errors where linkages following the CNR hierarchical structure broke down whereas alternative routes might be available in a non-hierarchical network. The CNR topology did not include second tier communications nodes such as appropriately placed retransmission stations.

with node movement over the terrain as the operation progressed. While the animations are quite effective in portraying the evolution over time of the effects of the communications connectivity, the production of the animations involves significant off-line effort by staff.

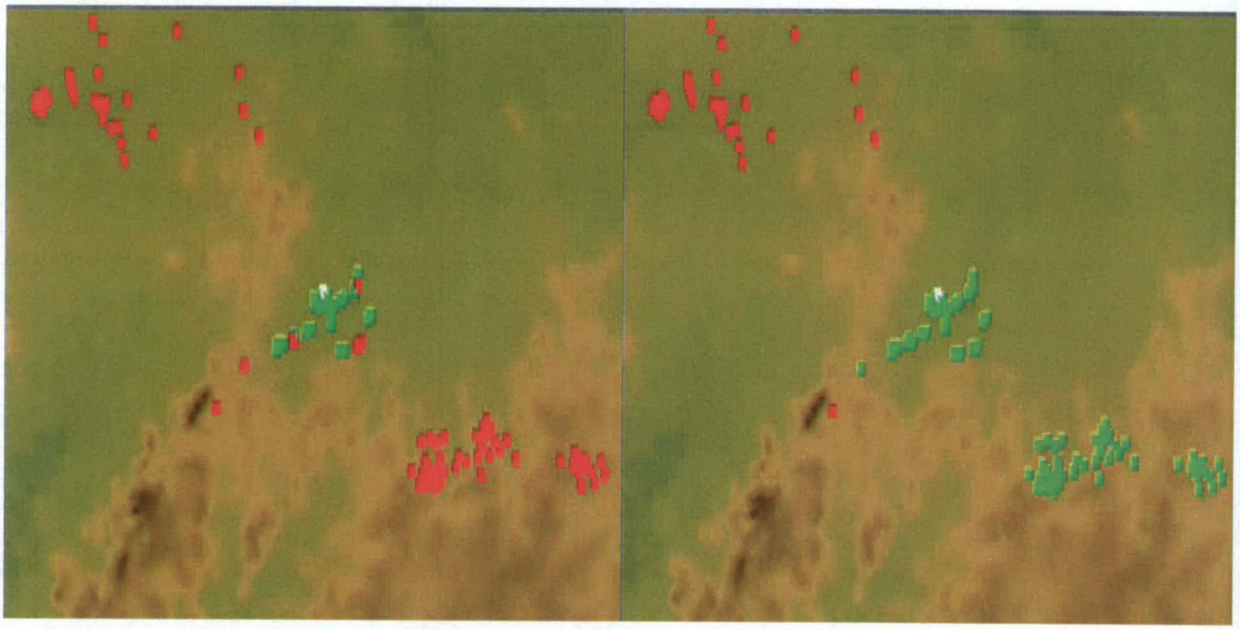

Figure 1. CNR TDDS Comparison[10]

5.2 Recent Radio Discrete Event Simulation Efforts

More recent modelling under JTW 02/098 uses a discrete event simulation of the radio network (see associated report [10]) and has included a position reporting system as a sample application.

An argument has been put [11] that modelling to extract the low level performance measures can also contribute to an understanding at higher conceptual (operational effects) levels. As an example one conceptual measure has been explored in the arena of location reporting. Visualisations can be produced similar to those obtained via the analytical approach but with the added utility of incorporating network capacity limitations. Moreover, this work has led to a proposal of a single digit global metric of position 'Knowledge'.

The discrete event simulation effort has implemented a simple 'knowledge' metric. This is the proportion of node-node pairs where the error (ie the understanding at one node of the other's position compared with the actual position) lies within a globally defined threshold. This assumes that it is essential that all entities have perfect knowledge of all

[10] The terrain colouring is from dark brown for high terrain through to dark green for low terrain.

other entities - clearly this is not necessarily true. An 'improved' metric has been developed; at each node it reflects the degree to which the picture it sees of the battlespace matched its doctrinal requirements. This then leads to a global knowledge metric that aggregates the individual node metrics weighted by some doctrinally derived factor reflecting the importance to the operational outcome of each individual node having good friendly situation awareness.

Investigations continued into the development of performance models under DSTO Task LRR 02/303. The work extended the analytical exploration using a discrete event simulation (bespoke development rather than one based on the Opnet package used elsewhere by DSTO). The performance model developed has the potential to be used to investigate traffic performance statistics for different protocols, node connectivity varying over time and traffic flows. The outputs are more related to system performance modelling and not directly relatable to the position reporting problem. Nevertheless, the model does explore the interaction between position reporting traffic and other competing traffic types.

6. Conclusion

In this paper we have investigated the impact of those position reporting parameters that can be controlled by the user (use of thresholds for initiating reports etc). DSTO's Information Networks Division (IND) has developed models that can deduce from these parameters traffic models that could be used in quantitative investigations.

The ideal may be for commanders at any level to be able to zoom in to detail any forces in the battlespace and to have sensor-controller-shooter communications links of unrestricted capacity, however there are laws of physics and technological constraints that preclude this. While investigations continue into various architectures to satisfy these constraints, developing warfighting philosophies and methodologies need to be moderated by a knowledge of the supporting communications system capabilities.

In the meantime, position reporting doctrines need to be carefully considered in the context of who needs to know the information and how often does the information need to be updated. Models that can assist in providing quantitative and qualitative analysis have been introduced to a wider readership in this paper and continue to be refined.

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Appendix A: Communications Networks Fundamentals

A.1. Point to Point Approaches

Point-to-point[11] approaches employ a spectrum of topologies from star (one hub and all other nodes connected only to the hub) to fully meshed (all nodes have a link to all other nodes). In this approach each node-to-node connection has its own radio assets at each end i.e. each link is dedicated. Often these radios operate in the full duplex mode, being able to transmit and receive simultaneously. The capacity of the network is the sum of each link capacity.

A network may not be fully meshed if there is a loss of a direct communications link between nodes. One might consider the capacity of the network to be the total of each link capacity. However, if the topology is not fully meshed then messages between nodes not directly connected will require relay. This requirement to relay due to the reduction in the number of links reduces the capacity of the network

A.2. Broadcast Shared Media

Broadcast (more specifically all-informed) networks are the simplest to quantify capacity. In a pure broadcast network all users can communicate directly to all others simultaneously. The wireless medium is shared by all nodes, and at each node there is only one radio on the network. The implications of such an approach in the Land Battlespace are:

- Broadcasting messages are intrinsically supported – one broadcast message can be sent with one transmission.
- The medium is shared, so in principle the capacity of an individual node to transmit is inversely proportional to the number of nodes on the network.
- Media access control disciplines find it difficult to minimise/eliminate collisions (two nodes transmitting simultaneously) yet maintain efficiency. This is further complicated in the wireless case as it is typically not possible to receive and transmit at the same time on the same frequency.
- Shared media networks become harder to operate effectively as the number of nodes increases.

An extension of this approach used widely in the tactical land environment is to arrange small sub-networks (nets) in a hierarchy based upon the command hierarchy. This is illustrated in Figure A-1. Each net is independent and in principle can operate simultaneously without interfering with other nets through the allocation of separate radio frequencies. Selected nodes (typically command elements) act as net control stations of subordinate nets and have a second radio as a member of the superior net. Messages

[11] The content of this Appendix is drawn from unpublished work by Mr P Clark, IND

between nodes in different nets require relay at these net control stations up and down the hierarchy. One might consider the capacity of the network to be the total of each net capacity. However, the need for relay reduces the effective capacity of the network. If information must be passed from all nodes to all other nodes then the effective capacity of the network is equivalent to the capacity of a single net.

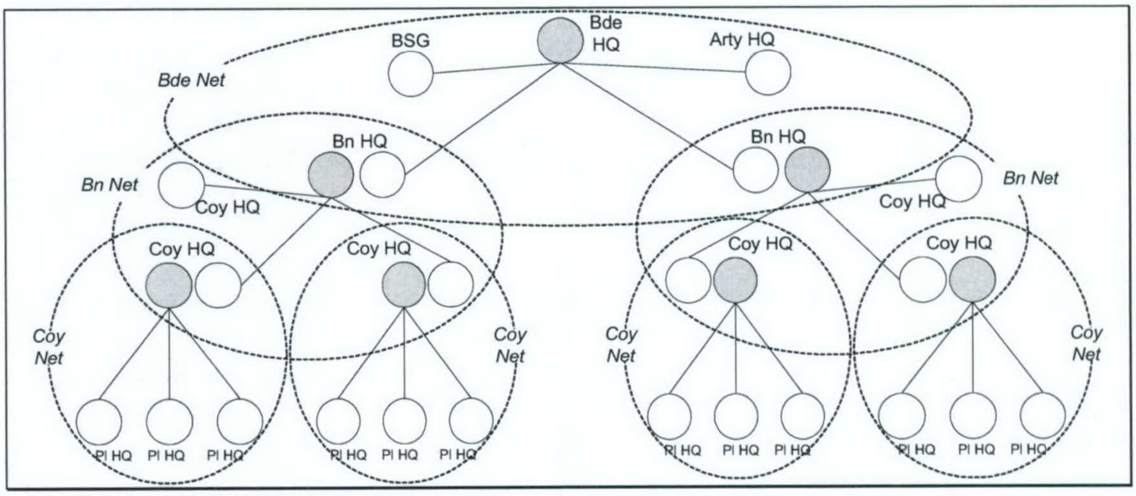

Figure A-1. Indicative CNR Net Structure[12]

A.3. *Ad Hoc* Flat Topology

In the context of wide area networking and in the purest sense, an *ad hoc* network is an autonomous system of mobile nodes connected by wireless links. The nodes are free to move and interconnect independently and the resulting network topology is not pre-determined. In a land tactical environment, the connections and topology are driven by radio performance and are not directly determined by organisational affiliations. Each node typically has one radio operating in a broadcast medium. Media access control and traffic routing is a significant challenge. Messages will often require relaying (reducing effective capacity) but there is scope for some parts of the network to operate simultaneously (increasing effective capacity). The total effect depends on network topology and the nature of the traffic being carried. The applicability of *ad hoc* networks to military communications systems is an area of on-going research.

Key advantages of an *Ad Hoc* network architecture are that:

- nearby nodes, which may have a community of interest, are likely to be a small number of hops apart; and

[12] For the purposes of clarity only, the figure depicts a star configuration with each sub-station operating a link to the net control station. In fact the net operates as an all-informed broadcast net, ie any transmission is heard by all other nodes simultaneously. Retransmission stations are deployed to maintain this all-informed performance.

- a degree of range extension is achieved in that a node no longer has to be able to reach other members of his command hierarchy to intercommunicate - only be able reach another *ad hoc* network member.

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19. ABSTRACT

A fundamental of Network Centric Warfare is situational awareness. Situational awareness includes knowledge of own force combat effectiveness, positions and intentions. The method of disseminating the knowledge of own force positions and how current that information is are the subject of much discussion. The universal distribution of perfectly synchronised position information over the land battlespace is likely to be impossible due to constraints in communications capacity. This report considers the trade-offs between complexity of processing, communications capacity and accuracy of position information. It draws on modelling efforts within Information Networks Division that may assist in considerations of a trade-off study.

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