Chapter 3 – ARMY TACTICAL COMMAND, CONTROL AND COMMUNICATIONS ENVIRONMENT

The issues discussed in Chapters 4, 5 and 6 require a clear understanding of the constraints imposed by the tactical command, control and communications environment. An overview of this communications environment is described in the present chapter, based on an Army command and control structure. Marine forces deployed ashore tend to be smaller in size, but face most of the same challenges when employing land based radio systems to coordinate their actions on the ground.

3.1 MILITARY COMMAND AND CONTROL SYSTEM STRUCTURE

Command and control systems must support three types of relationships: command, support and proximity. The following extract is taken from [1]:

> "Command relationships exist whenever one unit or formation commander is a direct subordinate of another…Command requires a rich bi-directional exchange of information between the higher headquarters and the subordinate headquarters. The purpose of this exchange is to pass command information (plans, orders, task organization, battlefield geometry, alerts, warnings and status) between the two headquarters. This type of information exchange follows the parent-child relationship. The superior (parent) headquarters supplies directive information to the subordinate (child) headquarters – higher to lower; the subordinate (child) headquarters provides status information to the superior (parent) headquarters – lower to higher.
>
> Support relationships are a particular type of command relationship. Support relationships are established when one organization must aid, protect, complement or sustain another force. In the context of Command and Control (but not, for example, fire control) these organizations have the same requirements for information exchange as command relationship. Support relationships are of two types: Direct Support and General Support.
>
> Proximity relationships exist when units with no direct command or support relationship are operating in proximity to each other and must exchange non-command information in order to establish and maintain situational awareness. Examples of this type of relationship could be the flank coordination of adjacent tank and infantry battalions or the forward passage of lines of an armoured regiment through a mechanized infantry battle group. In proximity relationships, information flows horizontally between the headquarters of the units involved as peers, not parents/children. Units involved in proximity relationships may be subordinate to different higher headquarters."

The military command and control structure is hierarchical (Figure 3-1). A headquarters at a certain command level will be parent of one or more subordinate headquarters, and will itself be subordinate (child) to a higher headquarters. The communication infrastructure and flow of information over that infrastructure reflects this command hierarchy. A commander at a given level will generally be required to maintain information from one level up and two levels down in the command hierarchy, as well as from flanking formations with which he has a proximity relationship.

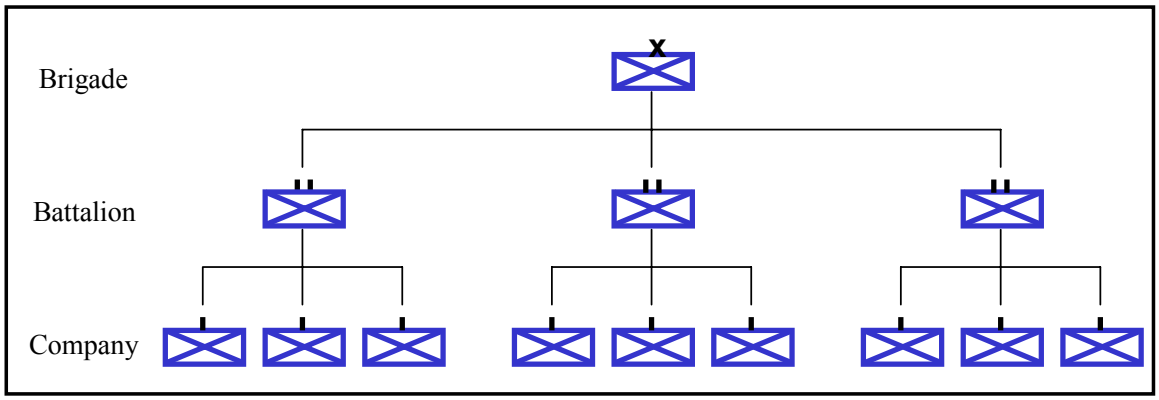

Figure 3-1: A Typical Hierarchy of Command Headquarters.

3.2 COMMAND AND CONTROL COMMUNICATIONS INFRASTRUCTURE

The command and control communications infrastructure is generally organized as a series of hierarchical subnetworks. A brigade command subnet will include a node at each of the three battalion headquarters under the brigade's command. A battalion command subnet may have a dozen or more nodes, but will include a node at each of the three company command posts under the battalion's command. Links from battalion headquarters to brigade or higher headquarters are typically provided by relatively reliable and high bandwidth satellite links or dial trunk systems employing wire or wideband microwave links. The Task Group focused its attention on the Army battlefield environment forward of a battle group or battalion[1] headquarters in which all communication occurs between mobile nodes equipped with a combat net radio operating in either the Very High Frequency (VHF) or Ultra High Frequency (UHF) band. A radio subnetwork consists of a set of radios tuned to a common assigned frequency. The subnet is linked to an adjacent subnet through a relay or gateway node that is common to both subnets. The relay node contains two or more radios, each tuned to a different subnet frequency. A verbal message received at the relay node from a sending node on one subnet is recorded in writing by a human operator, and then retransmitted verbally on the appropriate subnet to reach the destination addressee(s) on that subnet, if required. A gateway performs the same function for a data transmission, except that caching of the received transmission, and retransmission on the target subnet(s), are handled automatically by the gateway.

3.3 COMBAT NET RADIO COMMUNICATIONS ENVIRONMENT

The discussion in this section is taken from [2]. Forward of battalion, communication occurs over line-of-sight (LOS) radios operating in the Very High Frequency (VHF) or Ultra High Frequency (UHF) bands. Most of these radios are vehicle-mounted, but man-portable versions are also employed. At the lowest echelon, such as an infantry section on foot engaged in urban warfare, soldiers may use short-range radios operating in the High Band UHF. These radios have ranges of 400 meters or less. UHF radios are used for medium-range LOS wireless communication from 400 meters to 15 kilometres. VHF Radios must be used where non-LOS communication beyond 15 kilometres is required.

[1] Battalions are either mechanized battalions (two armoured companies, one infantry company) or infantry battalions (two infantry companies, one armoured company). A battle group is a battalion augmented with other assets (usually engineer or artillery assets).

The vast majority of VHF combat net radios have base bandwidths of 16 kilobits per second (Kbps) half duplex[2]. UHF radios can have base bandwidths as high as 288 Kbps full duplex. High Bandwidth UHF radios can have base bandwidths as high as 11 Mbps. In spite of their limited bandwidth, combat net radios operating in the VHF band still predominate because of their greater range and beyond-LOS capability.

The values quoted above apply to the physical layers of the network, the lowest layer of the seven-layer OSI model (Figure 3-2). The reality is that the useable throughput at the application layer is a fraction of this base rate. Factors such as forward error correction (FEC), encryption overhead (e.g., crypto synchronization sequence), acknowledgement request and retransmission mechanisms at data link and transport layer, and media access control mechanisms, are responsible for this reduction. Moreover, the effective throughput at any time may fall well below this maximum value due to variations in the performance of the physical radio channel caused by real-world factors such as terrain interference, atmospheric interference, multi-path (reflections) and prolonged fading. Effective throughput can become zero for periods of time for certain links, or for the entire subnet (in the case of imposed radio silence).

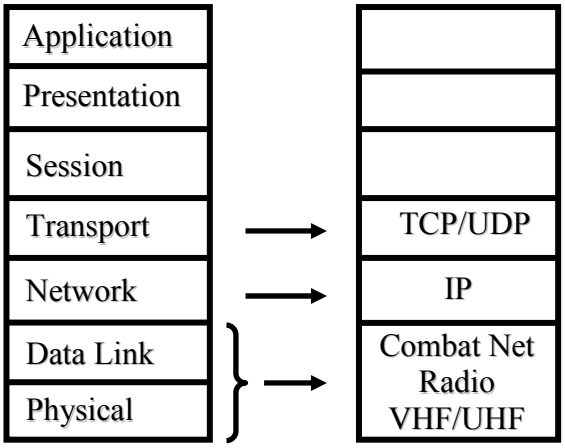

Figure 3-2: Seven-Layer ISO Network Reference Model.

A VHF combat net radio with a base rate of 16 Kbps may have a maximum effective throughput as low as 1 Kbps due to the factors quoted above. If ten users share the radio subnet, the maximum effective throughput per user will be only 100 bps. This figure assumes a data-only network with no voice contention for the channel. The reality is that the residual bit-error rate (BER) (i.e., the BER after error-control coding) for these radio channels can be as high as 10^{-5}.

One known UHF combat net radio can have a base rate as high as 288 Kbps. However, UHF radios have shorter ranges than VHF radios since the higher frequency UHF waves are more susceptible to the real-world factors quoted above. For the case considered, field measurements suggest that the maximum effective throughput at the top of the data link layer in a tactical environment would be approximately 16 Kbps for a link with a 22 Kbps base rate and approximately 80 Kbps for a link with a 100 Kbps base rate. For a subnet with 10 users, maximum effective throughput per user would be 1.6 Kbps and 8.0 Kbps respectively. Residual BER are similar to rates experienced with VHF radios.

[2] Half duplex means that the radio can either send or receive on the same channel, but cannot simultaneously send and receive. Full duplex means that the radio can simultaneously send and receive on the same channel.

In the Internet world, the transport protocol of choice for most applications is the Transport Control Protocol (TCP). TCP provides reliable packet delivery using a sequencing and positive acknowledgement scheme and is a connection-oriented protocol as it establishes a connection with each recipient. Although point-to-multipoint addressing schemes are being developed for TCP, in the radio domain the vast majority of systems still use a point-to-point addressing scheme for TCP. Therefore, in this domain, if a transmission is intended for *N* recipients, it must be sent *N* times. In a highly bandwidth-constrained wireless environment, the communication overhead associated with the use of a connection-oriented transport protocol like TCP is generally unacceptable. As well, the congestion-control mechanisms used by TCP were developed for the wired domain. TCP interprets latency and packet loss as evidence of congestion, to which its reaction is to throttle back the offered load to the network. This results in a significantly lower TCP throughput than the network can actually provide. In low bandwidth, high latency, and relatively high error networks like those found in the tactical radio domain, many TCP connections would be terminated due to these effects. User Datagram Protocol (UDP) is a connectionless alternative to TCP. However, UDP is unreliable since it does not employ sequencing or acknowledgement. Custom middleware operating just above UDP may be required to optimise reliability of packet transmissions in a connectionless, high BER tactical wireless environment.