# 4

# Development of Tactical Communications

## 4.1 Introduction

Early commanders were constrained in their sphere of influence by how far they could move away from their troops and still remain in physical contact. This restriction on their ability to command and control placed a limit on the number of troops that could be placed under their command. A larger number of troops could be commanded through the development of a chain of command that provided a hierarchical structure within which orders could flow up and down between superior and subordinate commanders. Each commander still had to remain in physical contact with superior and subordinates, however. To embark on large-scale military endeavors, commanders needed to communicate effectively over distances larger than shouting distance and some form of communications system was required. Early systems were rudimentary, utilizing visual and acoustic signaling as well as messengers. The introduction of telegraphy and telephony saw the beginnings of a major change in command and control capability, and tactical communications systems have grown in complexity and scale to become an indispensable component of a commander's warfighting capability [1].

This chapter begins by briefly examining the early history of military communications and then focuses on the development of the two major tactical communications subsystems that are deployed by all major modern armies. From this background, a number of fundamental principles of battlefield communications are identified to provide a detailed understanding that can serve as a basis for subsequent analysis of the communications support that can be provided to modern tactical commanders.

## 4.2 Early History of Battlefield Communications

### 4.2.1 Early Military Communications

It made sense for early commanders to extend their controlling capability by using some extension of their physical means of communication. Early communications systems therefore took one of two simple forms: the *relaying of a message* by runner or courier, or *signaling* by some visual or acoustic means.

For several thousands of years messages between commanders have been carried by runners, either on foot or mounted on horseback. Messengers provided one of the major means of communications throughout both world wars and still provide an essential service today in transmitting bulky information around the battlefield. The means of transport has changed considerably, however. The horse was used until the end of World War I and was gradually replaced from the early 1900s by motorized transport in the form of the motorcycle and motorcar and, more recently, by aircraft.

Apart from human couriers, a number of animals have also often been used to transport messages [2]. For thousands of years, pigeons have been used to carry a message in a small tube attached to one leg. The British made the first large-scale use of pigeons during World War I with tens of thousands of birds in service. Although the birds were also used in World War II by infantry, armor, and aircrew, pigeons have not been used seriously since [3]. During World War I, the Germans and the British also briefly used dogs as messengers.

Early communications systems also extended ranges by relaying a message by shouting it between men stationed every hundred yards or so. Cannon shot, trumpet blasts, and drumbeats were also used to transmit simple messages over longer ranges. However, most early communications systems made much more use of visual signals than acoustic due to the longer ranges possible. Fire, smoke, rockets, flags, mirrors, and windmills were all used as simple signaling systems, and signaling range was often increased by building towers. Longer ranges were also possible after the invention of the telescope in the early seventeenth century.

In the late seventeenth century, a number of optical telegraph systems [4] were developed to transmit signals by placing mast-mounted beams or discs in different positions. For example, the French Radiated Telegraph machine could transmit 196 different signals (letters, code words, or phrases). Incidentally, communications were secure, since a codebook was required to decipher the signal. Optical telegraphs rapidly became obsolete in the early eighteenth century with the invention of electrical telegraphy, although some relatively sophisticated optical systems such as the heliograph, signaling lamp, and semaphore flags continued in service until the end of World War I [5]. After the invention of the electric telegraph, almost all other forms of communication were quickly replaced by systems that made use of electrical signals.

### 4.2.2 Electrical Telegraphy and the Telephone

The first major tactical and strategic use of the electrical telegraph was during the Crimean War (1853–1856). Strategically, a submarine cable laid from Varna to Balaclava assisted in connecting the British and French commanders with London and Paris, respectively. The cable provided great frustration for both commanders as, for the first time, both were in intimate contact with their political masters. Tactically, the Crimean War saw the first deployment of a telegraph troop with two telegraph wagons, a cable cart, a plough, and 24 miles of copper wire. By the end of the Crimean campaign, some 21 miles of cable had been laid, interconnecting eight headquarters.

In 1859, the Spanish and French armies made use of electrical telegraphy, albeit with civilian equipment and civilian operators. In 1860 the Italian Army made the first use of purpose-built military telegraph equipment and military operators. During the American Civil War, both the U.S. Army Signal Corps and the Confederate Signal Corps made use of electrical telegraphy.

In addition to telegraphy, staff officers began to demand telephones, which had become more common in civilian life. The first use of telephony by the U.S. Army was during the Geronimo campaign in Arizona in 1886. Although the telephone was also adopted by other armies in the late nineteenth century, it did not develop into the important tool it is today until the early twentieth century. The Japanese made the first extensive tactical and strategic use of the telephone during the Russo-Japanese war (1904–1905).

During World War I, line telegraphy provided the major means of communication. Most lines were buried well below the surface to protect them from artillery. The immobility of the buried cables and the sheer number of them forced better cable planning, and a grid system of main arteries into which units and formations could connect was developed. Each divisional area had a main artery with switching and testing centers connected to the main arteries of the division on either flank, thereby forming the grid system. Hundreds of miles of cables were deployed to support any advance until the grid system could be extended to cover the new positions. Tactical circuits were then connected to strategic telegraph circuits to allow the transfer of orders and information from headquarters to field commanders.

Telegraphy was the major means of communication during World War I, although telephony also grew in popularity since it gave staff officers timely, personal contact. So, in addition to line testing centers, telephone-switching centers sprung up all over the battlefield.

### 4.2.3 Radio

At the beginning of the twentieth century, line communications were augmented by the new technology of wireless communications. Although the British Army introduced a reasonably reliable set in 1915, radio telegraphy was not readily accepted throughout World War I, as the technology was still immature and radio telegraphy was sometimes inefficient, mostly due to a poor understanding of the physical processes involved and the low frequencies used. Despite that, radio telegraphy was much more flexible than line telegraphy and it was not long before tasks such as gun registration were being conducted by radio instead of line. For most tasks, however, radio was not well accepted in a static war where the telephone worked well.

At the beginning of World War I, all communications were via line from Army HQ down to company level. Radio communications were very limited. Communications followed the chain-of-command and had the same hierarchical structure. Communications from division to battalion levels were provided by the divisional signal company. Communications from battalion to company and below were provided by regimental signalers. By the end of the war equipment had improved, but not much had changed doctrinally except that the use of radio had increased to provide alternative means to line, particularly in communications below brigade where mobility was important. Line, however, remained the primary means of communication, with tens of thousands of miles of cable being laid by all sides. Line was still unreliable in some theaters and heavy use of dispatch riders or runners was made.

### 4.2.4 Between the Wars

Between the wars there were a number of developments in technology. The perfection of the vacuum tube allowed the consistent amplification required for AM. This allowed the first voice radio sets, or radiotelephone sets, to be introduced in 1918. Another important advance between the wars was the teletypewriter, or the printer telegraph. The teletypewriter required more power and was more complex to maintain than the Morse telegraph, but it was more accurate, faster, and relatively simple to use. The field telephone set was also developed between the wars and the Germans developed a small switchboard, which was rapidly copied by most armies.

During the 1930s, radio sets were developed to meet the needs of the infantry, artillery, armor, and aviation corps to provide the necessary mobility, range, and reliability. In 1934, the United States developed the 25-pound radio that became the first walkie-talkie. Between the wars radio sets became smaller and were carried on a number of platforms. The horse was finally replaced by the motorcar, leading to the mechanization of both radio wagons and cable wagons.

### 4.2.5 World War II

During World War II radio become ubiquitous across the battlefield, used extensively at the tactical level for the first time. The first armored command vehicle appeared and radios provided the necessary communications within highly mobile forces, often widely dispersed. FM radio was developed to provide noise-free communications. The infantryman was issued with a man-portable radio, which greatly enhanced operations. At the beginning of the war, only a few radios had been provided for catering to the main command links of formations, for divisional artilleries, and for internal use in armored and artillery units. By the end of the war, radio was used to conduct all essential tactical and administrative communications. The main reason for this was the inability of the line to keep up with highly mobile, widely dispersed forces often operating in inhospitable terrain. Headquarters required at least two operational command links, one for telegraph traffic and the other for voice. In addition to command, independent radio systems had developed for intelligence, air support, artillery, engineers, supply, and other services.

Line communications continued during World War II, although mostly for telephony work. World War II saw the integration of all forms of line and radio communication into high-quality links, regardless of the medium. Multichannel trunk radio made its first appearance in during the war, albeit in a simple form with up to eight duplex channels being provided by the British No. 10 set, one of the few World War II radios to operate in the UHF range. During the rapid advance eastwards from Normandy toward the end of the war, the line could not keep up and radio relay began to provide its utility on the support of fast-moving operations.

Although there were very few advances in communications technology in World War II, at the end of the war the face of military communications had changed considerably. While line was still utilized as an important medium, the mobility and dispersion of the battlefield had reversed the World War I situation so that radio had become the prime means of communication and line was only used as a secondary means when time allowed it to be laid. The communications provided by divisional signal units were higher-capacity radio and line links from division to brigade and brigade to battalion. Below battalion, lower-capacity radio and line links were provided by regimental signalers.

### 4.2.6 Current Doctrine

Two distinct battlefield communications systems have therefore developed to support the tactical commander. The first, above battalion, required high capacity links provided by the formation to interlink supported units with headquarters. The links were usually duplex and were limited to be from one unit to another. For example, a headquarters had a link to each of its subordinate units. These types of infrastructure links became known as *trunk communications* in line with their commercial equivalents. More commonly, as the links became more radio than line, they became known as *trunk radio*. Still, line is an important medium on the modern battlefield, and is laid within headquarters by hand reel and over larger distances by vehicle.

The second type of communications developed to allow units at battalion and below to perform tactical tasks. These links were flexible and responsive, under the direct control of the commander. Links were established using single-frequency, half-duplex, all-informed radio nets allowing the commander maximum flexibility to command a number of subunits. These types of communications have become known as *single channel radio*, or more commonly as *combat net radio*.

Overlying both of these services was still the requirement to send and receive bulky communications. These needs were still being met by dispatch riders of the signal dispatch service (SDS) or postal service. As we saw earlier, SDS is provided by a wide variety of forms of military transport: motorcycle, vehicle, and aircraft.

So, two broad types of communications service have evolved: combat net radio, or single channel radio, and trunk communications (including line, radio, and SDS). Doctrinally these divisions still exist on the modern battlefield, albeit in more sophisticated forms.

- *CNR subsystem.* The CNR subsystem is a ruggedized, portable radio (HF, VHF, and UHF) network carried as an organic communications system for combat troops (brigade level and below). Radios are invariably interconnected to form single-frequency, half-duplex, all-informed, hierarchical nets, providing tactical commanders with effective support to command and control.
- *Trunk communications subsystem.* This subsystem provides high-capacity communications links down to brigade level. The subsystem traditionally comprises multichannel radio equipment, line, switches, and terminating facilities to provide voice, telegraph, facsimile, and data communications, as well as a messenger service.

These two subsystems are described in more detail in the following sections. It should be noted that in U.S. doctrine, a third subsystem, the Advanced Data Distribution System (ADDS), is provided—the need for this third element is discussed in Chapter 5, and a more detailed description is provided in Chapter 8.

## 4.3 CNR

All CNR stations on a particular net operate on the same frequency in a shared channel, as illustrated in Figure 4.1. Each station can transmit and receive, but not at the same time. CNR systems are therefore often referred to as single-frequency, half-duplex in nature. To access the net, all stations operate using a simple CSMA-like procedure. When the net is free, any station can initiate a call. However, since the communications channel is shared in a half-duplex manner, users must use a protocol to determine the right to talk at any particular time. In traditional voice communications, this protocol [called *voice procedure* or *radio telephone (RATEL) procedure,* or *radio operating procedure*] [6], is based on the use of call signs for the beginning of conversations and keywords for handing over the right to speak, and for the termination of conversation. Additionally, a higher level of control is normally forced on the network by one of the stations called the *net control station* (NCS), which is responsible for running the net, including net discipline and control of frequency changes.

The significant military advantage of such a net is that it is *all-informed* in that each station receives all transmissions from all other stations whether they are intended for it or not. This configuration is essential for command

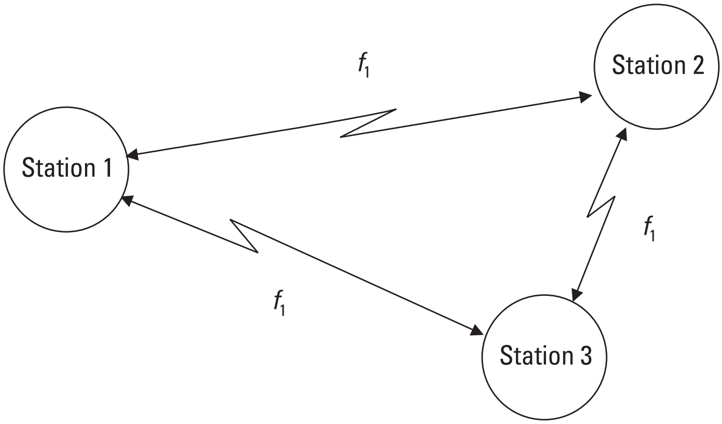


**Figure 4.1** Single-frequency, half-duplex net.

and control because it allows commanders to pass orders efficiently to a number of subunits without having to repeat calls. Similarly, commanders can monitor activities by monitoring the net traffic without specifically having to request a report. The all-informed nature of the CNR net does have a limitation, however, due to the requirement for all stations to be able to hear the transmissions from all other stations. The range that the net can cover is therefore limited, although stations can be used to pass on transmissions if one of the stations can only hear a limited number of transmissions. Extended ranges can also be obtained by the use of manual or automatic rebroadcast stations, which can provide coverage into other areas.

Single-frequency, half-duplex operation is the most suitable for CNR since it provides the maximum flexibility and survivability. To provide these qualities, however, in addition to the other military requirements of reliability, security, and capacity, individual military radios designed for CNR systems are generally expensive, heavy, and bulky and will normally constitute almost a full load for one individual.

CNR is normally provided in three frequency ranges: HF, VHF, and UHF. HF CNR is normally provided with a frequency range of 2 to 30 MHz. Voice is transmitted in a 3-KHz channel using SSB. VHF CNR in most armies is capable of operating in the frequency rage of 30 to 88 MHz, although greater ranges are sometimes encountered. Channel spacing in older analog systems is 50 kHz, but is now commonly 25 kHz providing FM voice. Data is transmitted using a form of FSK, to provide a signaling rate of 16 Kbps in the available 25-kHz channel.

Although CNR nets are single-frequency, all-informed nets, they are operated in a hierarchical manner and are generally used to reinforce the chain-of-command. That is, the NCS is normally collocated with the commander and the net is normally viewed as having the architecture shown in Figure 4.2.

When nets are employed to support a military command structure, commanders are invariably on at least two nets to remain in contact with their superior as well as their subordinates. Figure 4.3 illustrates a simplified version of the command nets for a division. Note that each commander requires access to two radios, which are not necessarily connected. The implications of this hierarchical net structure are discussed further in Chapter 5.

Use of the RF spectrum on the battlefield is dictated by a trade-off between capacity, mobility, and range. These issues have a considerable impact on the use of radios on the battlefield and are discussed in much more detail in Chapter 5 [7]. For the moment, Table 4.1 lists the traditional applications of the RF bands to use in CNR nets.

As discussed in Section 4.2, radio was first used on the battlefield for trunk communications as an alternative to line. Soon, however, radio was used for previously difficult tasks such as connecting forward observers to artillery batteries, which avoided the laying of hundreds of miles of cable to support major offensives. As sets and antennas reduced in size, they began to be employed to form artillery-infantry nets and infantry-armor nets. By the end of World War II, the United States had deployed CNR to most elements of the infantry and other arms.

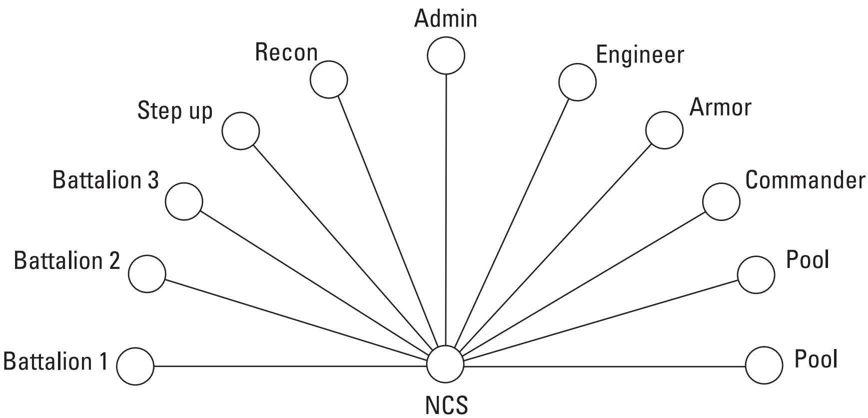


**Figure 4.2** CNR net diagram for a notional brigade command net.

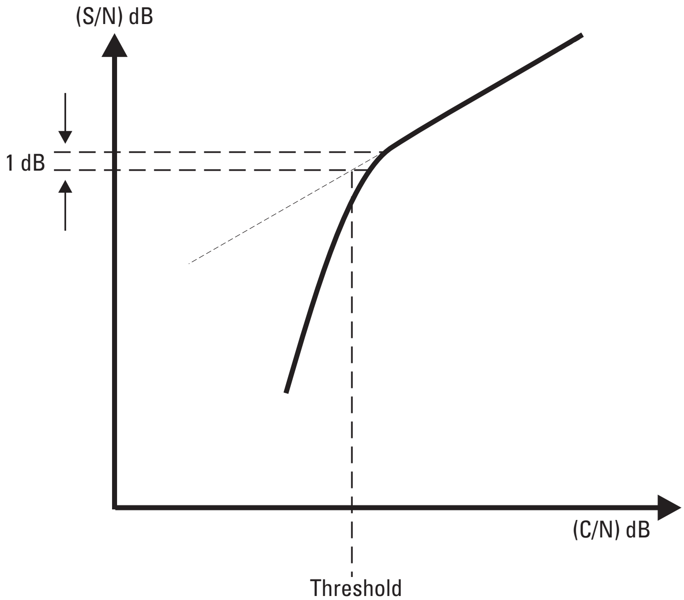


**Figure 4.3** CNR net hierarchy for a notional division's command nets.

Since CNR was first deployed, there have been a number of advances in technology. Electronic design has improved dramatically and modern CNR makes use of frequency synthesizers, integrated ATU, and more efficient antennas. Synthesizer design, in particular, has allowed radios to be capable of tuning across a number of bands. Sets have become lighter, smaller, and more reliable due to smaller integrated-circuit components, which require less space, power, and maintenance. There have been some improvements in battery technology that reduces the overall weight of the radio, although the battery remains the heaviest component of the system. Cryptographic equipment has become smaller, and is now commonly integrated into the set or handset. Over-the-air rekeying has eased considerably the burden associated with cryptographic key management and distribution across the battlefield. Finally, better modems have allowed CNR to operate at higher data rates, although the radio is still fundamentally a terminal on a voice network and is therefore not ideally suited to acting as a data network node.

Despite these evolutionary developments, the doctrinal use of CNR has remained largely unchanged since World War II. The major difference is in the ability to pass data over most CNRs, although most in-service CNRs are still analog radios and are not well placed to cope with the expansion in the

**Table 4.1**
Application of RF Bands to CNR Nets

| Band | Application to CNR Net | Advantages | Disadvantages |
|---|---|---|---|
| HF | Company, battalion, brigade, command, and administration nets<br>Rear links<br>Strategic interfaces<br>Armored, engineer, artillery, and reconnaissance nets<br>Special forces patrols | Cheap, man-portable, long-range<br>Graceful degradation of communications | Short surface-wave range from man-pack and vehicle whips<br>Relative immobility for sky-wave communications;<br>Limited number of frequencies and small bandwidth available |
| VHF | Platoon, company, battalion, brigade, command, and administration nets<br>Armored, engineer, artillery, reconnaissance nets | Represents optimum trade-off between bandwidth, power, weight, and size<br>Sufficient bandwidth available for encryption<br>Higher quality | Weight, particularly including encryption<br>Range limited to radio horizon because of low antennas |
| UHF | Squad and platoon nets<br>Artillery between guns<br>Ground-to-air nets<br>Special forces patrols | Lightweight, hand-held<br>Short-range, which reduces probability of intercept | Line-of-sight limits range<br>Not easily interfaced to VHF CNR |

*From:* [8]

volume of data expected to support concepts such as network-centric warfare. These issues associated with CNR on the digitized battlefield are discussed in more detail in Chapter 7.

## 4.4 Trunk Communications

Within a major headquarters or logistics installation, commanders and staff officers are connected by means of local links to a central headquarters hub. The links may comprise a LAN (for data), local loops (for telephony) or perhaps a single converged system. The hubs provide subscribers with connections to other subscribers within the headquarters using the local network; as well as with remote access to the combat radio network and access to the trunk network. The following sections provide a brief description of the development of trunk networks from rudimentary chain-of-command networks providing voice and telegraph, to modern area trunk systems providing the full range of subscriber facilities.

As illustrated in Figure 4.4, first-generation trunk networks provided communications links that followed the chain-of-command. This arrangement made sense, as it provided communications links that supported the flow of information, which was between commanders. Commanders also saw this as a natural arrangement as the doctrinal flow of information was up and down the chain-of-command. In fact, doctrine generally prohibited—and in most armies still prohibits—any communications outside the chain of command.

Direct chain-of-command networks had the serious disadvantage, however, that each headquarters was required to act as a tactical base as well as a communications node. These two roles are mostly in conflict. A communications node requires access to sufficiently high terrain to provide the range necessary to reach the superior headquarters as well as to the headquarters of subordinate units. In a tactical environment, in contrast, the commander must

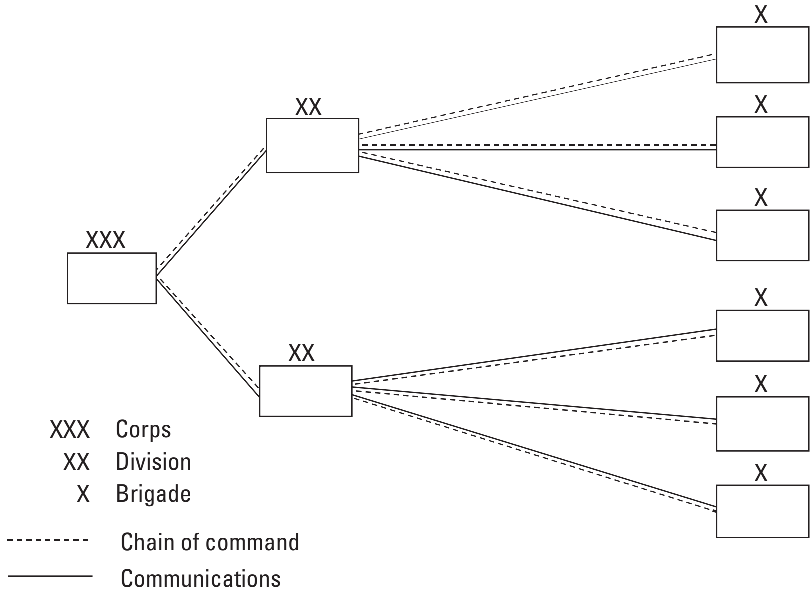


**Figure 4.4** Direct chain-of-command trunk network.

conceal the location of the headquarters since it is too vital an asset to have perched on a hilltop. The collocation of the communications equipment with the headquarters also constrained the mobility of the headquarters and increased its vulnerability to both visual and electronic detection. Additionally, any movement of the headquarters or damage to the network caused a disproportionate disruption to communications. For example, if the communications are lost to brigade headquarters, there is no mechanism for communications between the divisional headquarters and that brigade's battalions.

Figure 4.5 provides an example of a *second-generation trunk network*, which alleviated earlier difficulties by taking the logical step of displacing communications from the chain of command. By creating a physically separate communications site (often known in the British system as a communications center) that communicated to the headquarters over short cable or radio links, a separation of the tactical and communications roles of the headquarters was achieved. As a result of this separation, tactical headquarters and communications sites could be planned with a higher degree of independence, although the headquarters was still constrained by having to be near its communications center.

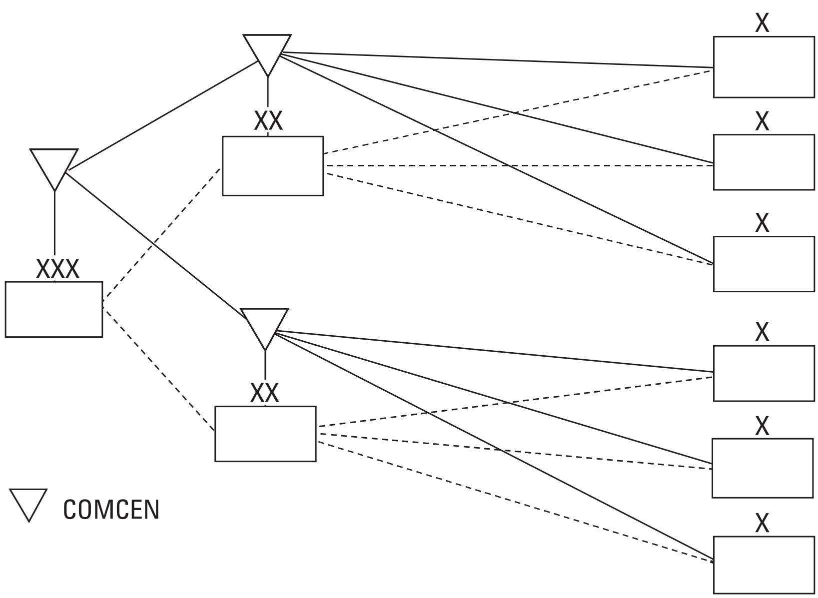


**Figure 4.5** Displaced chain-of-command trunk network.

Examples of this type of network include the early networks deployed after World War II, particularly the British Army's BRUIN network deployed in northwest Europe from the 1960s until 1985 when it was replaced by PTARMIGAN.

Although the siting difficulties were alleviated in the displaced chain-of-command network, any movement of the headquarters (or communications center) or damage to the network still caused a disproportionate disruption to communications. The next logical step was to improve the reliability of the network of the headquarters, providing a second communications center, which provided a second communications link into each headquarters and allowed one of the communications centers to be destroyed or moved without disrupting communications. The network could then be reconfigured without disrupting communications, thereby improving reliability. Figure 4.6 illustrates an example of this third-generation, *expanded chain-of-command network*.

The second communications center also allowed the headquarters to move using a process called *step-up* in which one-half of the headquarters deployed to the new location with one of the communications centers, set up, and established communications with the old headquarter location and the superior and subordinate headquarters. Command was then transferred to the new headquarters location and the old location was packed up with its

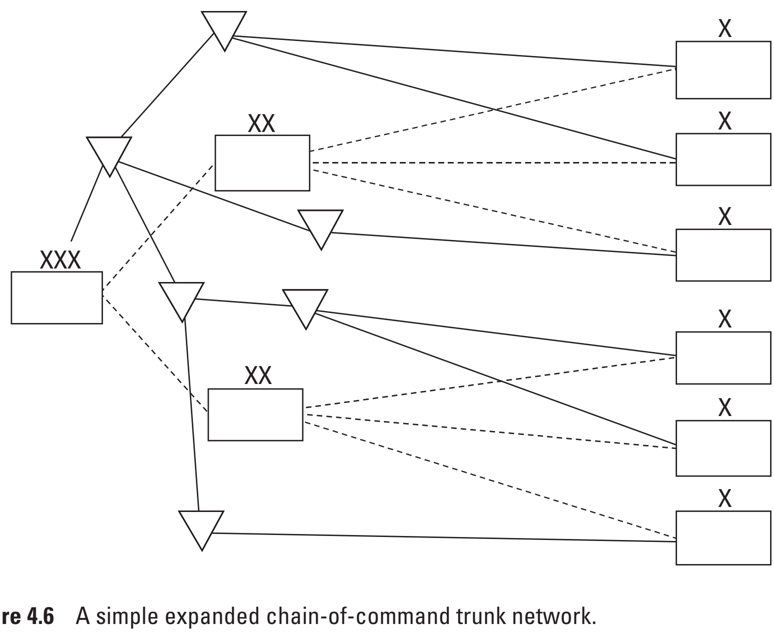


**Figure 4.6** A simple expanded chain-of-command trunk network.

associated communications center and moved to the new headquarters location. Perhaps the best example of a third-generation network is the U.S. Army's Army Tactical Communications System (ATACS), which was deployed until the mid-1990s when it was replaced by the Mobile Subscriber Equipment (MSE) trunk system.

### 4.4.1 Generic Fourth-Generation Trunk Communications Architecture

The logical extension of these developments is the fourth-generation area trunk network illustrated in Figure 4.7. Most modern trunk communications systems have been developed as fourth-generation networks. An area trunk network provides a grid (or mesh) of switching centers deployed to provide coverage of the area of operations. Nodes are interconnected by bearers, which are traditionally multichannel radio-relay links in the UHF or SHF band. Headquarters connect to the nearest trunk node by radio relay and can then have access to any other headquarters that is also connected to the network.

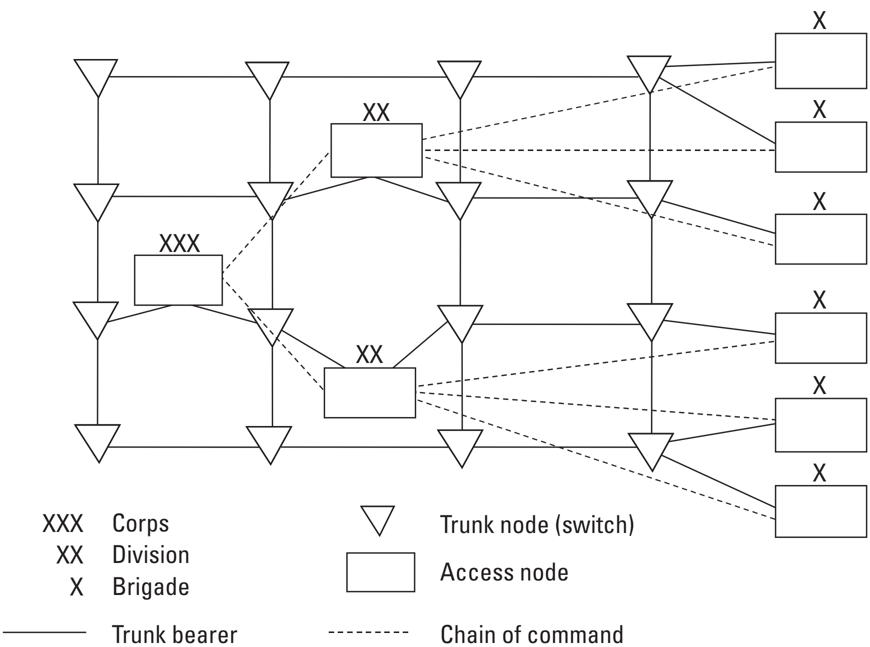


**Figure 4.7** A simple meshed area trunk network.

An area network contains significant redundancy and can sustain considerable damage, or cope with substantial movement, because of the alternative routes available. A key advantage of this network topology is its capability to automatically cope with traffic routing changes resulting from movement of subscribers or network outages. Nodes can be moved rapidly to reconfigure the network as required by the tactical situation. Commanders are no longer constrained by their communications links and can deploy as required by the tactical situation with the only siting constraint that the headquarters location must be able to communicate to at least one of the trunk nodes.

The obvious disadvantage of an area network is the significant amount of equipment and manpower required to establish the large number of redundant nodes. A first-generation network for a deployed corps required approximately 12 nodes for the major units; a fourth-generation corps network typically deploys 40 or 50 nodes. This disadvantage is by far outweighed, however, by the greatly improved flexibility, reliability, survivability, and capacity provided by an area trunk system.

### 4.4.2 Components of Trunk Networks

While each nation implements their trunk networks in slightly different ways, there are many common elements. The *trunk node* is the basic building block of the trunk network architecture. Nodes are connected together by multichannel *radio relay* links to provide a meshed infrastructure of trunk nodes. Headquarters and command posts connect to the network, and hence to each other, through *access nodes*. *Single channel radio access* (SCRA) provides full network access to mobile subscribers, and combat-net radio users are able to have a relatively limited interface to the network through a *CNR interface* (CNRI). Other trunk networks are accessed through a *tactical interface installation* (TII). Each of these components is discussed in more detail in the following sections. Components are discussed in generic terms, not related to any particular one of the national trunk networks listed in Table 4.2 [9].

#### 4.4.2.1 Trunk Nodes

As described earlier, the trunk node is the basic building block of the trunk network. Nodes are deployed and maneuvered to provide an area trunk network that allows combat units to deploy and maneuver as the tactical situation allows. Figure 4.8 illustrates the deployment of a trunk network in a generic deployment. Note that, as required by convention, the network

**Table 4.2**
National Trunk Networks

| Country | Trunk Network | Designation |
|---|---|---|
| Australia | PARAKEET | PARAKEET |
| France/Belgium | Réseau Intégré de Transmissions Automatique | RITA |
| Germany | Automatisierte Korps-Stammnetz | AUTOKO |
| Italy | SOTRIN | SOTRIN |
| The Netherlands | Zone Digital Automatic Communications | ZODIAC |
| United Kingdom | PTARMIGAN | PTARMIGAN |
| United States | Mobile Subscriber Equipment | MSE |

provides an interface to the network on the right, and has interfaces provided by the higher formation and the formation on the left flank.

Of course, Figure 4.8 does not accurately reflect the number of trunk nodes likely to be deployed in each area. Typically there are approximately 40 trunk nodes in a corps network, with approximately four allocated to each division and the remainder allocated as corps assets. Figure 4.8 also shows a physical grid pattern of deployment. While the network is invariably deployed with a logical-grid connectivity, the location of the trunk nodes is dictated by the terrain and the tactical situation.

Nodes are deployed and redeployed by the network managers to adjust to the needs of combat forces as dictated by the tactical battle. Nodes can be redeployed to facilitate an advance or withdrawal, or movement to a flank. The density of the network can also be modified to provide sufficient capacity to cope with any changes in force composition and location. Figure 4.9 illustrates the basic components of a trunk node:

- *Switch.* The nucleus of each node is the switch vehicle, which contains a processor-controlled digital switch. In most modern networks the switch is currently an automatic circuit switch that incorporates an embedded packet switch. Current switches typically provide 16 or 32

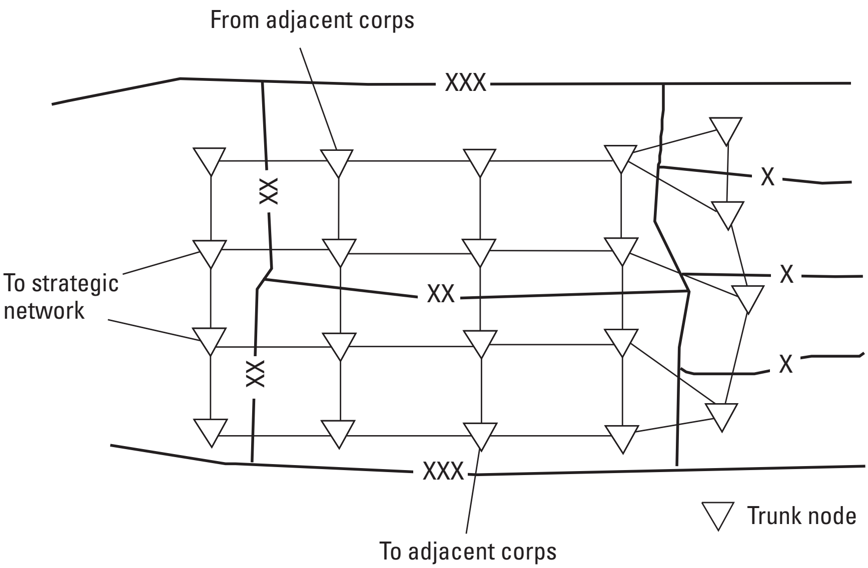


**Figure 4.8** Generic deployment of trunk nodes in a corps area.

internodal trunk channels. One channel is generally allocated to engineering and the remainder are bulk-encrypted and as internodal trunks. The meshed area network is created by connecting each node to at least three others through radio relay bearers.

- *Node operations center (NOC).* The NOC contains an operator interface to assist in engineering the switch and trunk encryption equipment as well as to allow some limited patching between trunk channels. The NOC would normally be located in the switch vehicle.

- *Network management facility (NMF).* The NMF performs link management for the radio relay links connected to the switch, including engineering of the links and frequency management. Normally some functions are also performed on behalf of the next level of management in the network. The NMF is normally a separate vehicle manned by the trunk node commander.

- *Radio-relay detachments.* In most modern networks, four or five radio relay detachments are typically deployed with each trunk node. Each detachment can terminate radio links from approximately three other radio relay detachments at either another trunk node, an SCRA *radio*

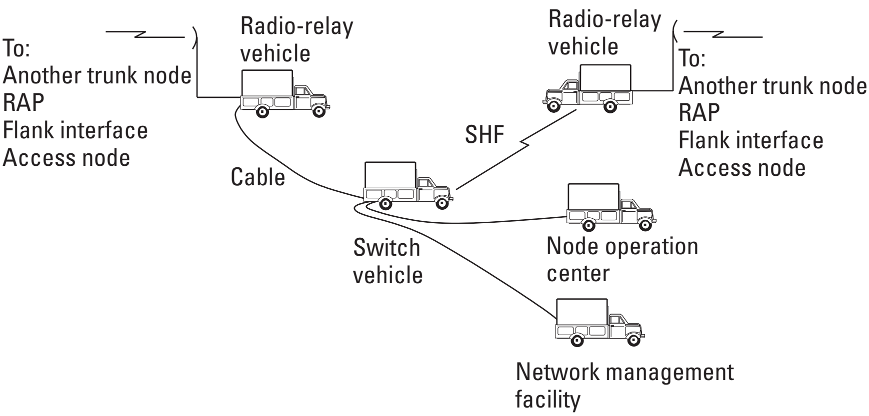


**Figure 4.9** The basic components of a typical trunk node site.

*access point* (RAP), a flank interface, or an access node. Detachments are normally sited on a suitable nearby hill and are connected to the node switch by a cable "tail" or, when the terrain does not allow cable to be laid, by SHF "down-the-hill" radio. Each node switch is normally connected through radio relay to other node switches to ensure a robust, survivable network, as illustrated in Figure 4.7.

#### 4.4.2.2 Bearers

Any wideband communications medium could potentially provide the multichannel, digital links between trunk nodes. Although sufficient bandwidth is available from coaxial cables, waveguides, and optical fibers, line of any type is very time-consuming to deploy and recover. Radio systems are far more flexible and are therefore normally the preferred method of linking trunk nodes.

##### *4.4.2.2.1 Radio Relay*

*Frequency of operation.* The most favored radio-relay systems operate in the VHF/UHF and SHF bands in order to provide the necessary bandwidth to interconnect trunk nodes. Within those bands, the frequency of operation of radio relay for a particular trunk network is selected as a trade-off between the need for high capacity (and therefore high frequency) and ease of antenna alignment (and therefore low frequency). At the high-frequency end, SHF systems are constrained by line-of-sight and limited to less than 12 GHz due to strong absorption by rain and other precipitation. For radio-relay applications, SHF systems therefore require careful selection of sites, high masts, and highly directional antennas, which require a long time to erect and align. These requirements normally prohibit SHF systems from meeting tactical mobility constraints that demand a short time into and out of action. SHF does have application, however, for short-range applications in down-the-hill shots from radio-relay vehicles to trunk nodes. For radio-relay applications, the VHF/UHF band is favored as a reasonable military compromise between adequate channel capacity and tactical mobility. Three bands are commonly utilized: Band I (225–400 MHz); Band II (610–960 MHz); and Band III (1,350–1,850 MHz).

*Antennas.* Radio-relay links are point-to-point, and directional antennas are used to make the best use of available power and maximize gain in the intended direction. Directional antennas are also very useful because they reduce the radiation in unwanted directions, which in turn minimizes the possibility of interception as well as reduces interference on radio systems in the near vicinity. For the receiver, a directional antenna minimizes the interference from other transmitters, including hostile jammers. The gain of these antennas is limited to about 10 to 25 dB so that the alignment and concealment are straightforward and the antenna is robust and light enough to erect quickly.

*Siting.* Radio-relay terminals located on high ground will give the best possible radio path. For tactical reasons, headquarters and trunk nodes are usually sited in more concealed positions. Since the two sites may be some distance apart, the radio-relay site is normally connected to the asset it is serving by a cable or, for longer distances, an SHF down-the-hill radio link. Sites are normally selected from a map reconnaissance and confirmed by a path profile analysis. This produces a short list of possible sites that are then subjected to a physical reconnaissance considering such factors as local obstacles not shown on the map; possibilities for concealment and camouflage; access for vehicles; and whether the site has already been occupied, since high features are always attractive for many other force elements, including radar, surveillance, EW, and communications detachments (noting that they are also attractive to adversary artillery units).

*Radio-relay range extension.* As noted earlier, although UHF and SHF frequencies provide sufficient bandwidth, they have the planning difficulty of requiring line-of-sight between antennas. Additionally, to maintain the required signal-to-noise ratios, particularly for data links, radio paths are limited to planning ranges on the order of 20 to 30 km. Often, therefore, two trunk nodes cannot be connected by one link and, as illustrated in Figure 4.10, an intermediate relay station, called a *radio-relay relay* station, is inserted in the link to extend range. This relay is sited so that there is a good line-of-sight path to both radio-relay terminals so that signals received from each terminal can be automatically retransmitted to the other. Where long internodal links are required to support widely dispersed forces, there may be several relay stations, although satellite or troposcatter links are generally preferred on long paths.

#### *4.4.2.2.2 Tropospheric Scatter*

From an application point of view, the most interesting characteristic of troposcatter radio links is the great distance over which reliable communications can be obtained without the need for intermediate repeaters. For example, troposcatter ranges would be on the order of 150 to 200 km, as opposed to tens of kilometers for radio relay. This feature is particularly useful for cases in which the terrain is difficult such as in connection between remote sites such as those in the desert or jungle; connection of a remote island to the mainland or another island, or across uncontrolled territory or geographic obstacles; and networks in which the possibility of sabotage at unattended repeater stations should be avoided.

The possibility of avoiding repeater stations, with their equipment, antennas, buildings, roads, and problems of accessibility and maintenance, may lead to a more economical solution with a troposcatter link instead of a traditional line-of-sight link. Troposcatter radio systems have particular application in less

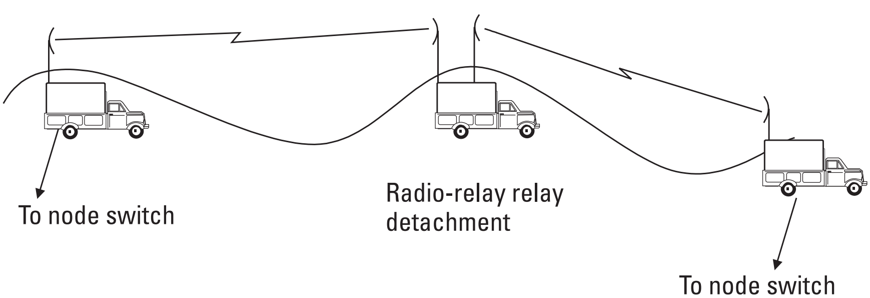


**Figure 4.10** Range extension using a radio-relay relay station.

conventional military operations where the security of repeater stations is an issue.

*Advantages of troposcatter systems.* The main advantages of troposcatter systems can be summarized as follows:

- They permit a long path. A single hop can have a length of hundreds of kilometers (five or six times the usual length of a line-of-sight link). They therefore fit neatly between line-of-sight communications systems and satellite communications systems, providing much more bandwidth than HF systems.
- They can be used on difficult terrain, which has little influence on the system design. This is particularly useful when the terrain has not been secured or, for example, when repeaters would have to be located above the snow line.
- Coverage of very large areas can be obtained with a small number of hops.
- Only a few repeaters are required because of the long hop-length.
- Fewer frequencies are required because of the reduction in the number of stations.
- Security against sabotage or catastrophic failure is easier to achieve, as there are fewer stations to protect.
- Procurement and operating costs are reduced because of the lower number of repeaters.
- There is a high immunity to interception because of very narrowbeam antennas.

*Disadvantages of troposcatter systems.* The main disadvantages are as follows:

- The cost per station is high. However, this factor may be superseded by the advantages given above and the troposcatter solution may be the most cost-effective choice as the overall costs (investment, operation, and maintenance during the life of the link) may be less than any alternative solution.
- High-gain antennas are difficult to orientate accurately.
- Antennas must have an unobstructed view of the horizon.
- There is a high RF hazard from the high power output at the antennas.

- There is a risk of interference over a wide area if the same frequencies are used at other stations.

Troposcatter was used in a combat environment for the first time by U.S. forces in 1962 to provide a backbone communications system that extended the length of South Vietnam [10]. Interestingly, the only U.S. National Guard communications unit deployed to the Gulf War was equipped with the TRC-170 troposcatter equipment [11]. Troposcatter remains a useful bearer system as part of a trunk communications system.

#### *4.4.2.2.3 Satellite Network Links*

Fourth-generation trunk networks were developed to provide reliable, survivable communications across a corps area within a high-intensity deployment. With the demise of the Cold War, a broader spectrum of operations has placed greater demands on meshed-network architectures. The first major change came in the Gulf War, where despite supporting corps deployments, trunk networks had great difficulty in providing a meshed architecture while keeping up with the rapid rate of advance. In fact, networks were invariably deployed in a linear fashion, requiring switch software to be reengineered to cope with the increased length of the networks from one end to another. Radio-relay bearers are ideal for a high-density deployment, but do not provide a good bearer system for rapid movement of supported forces over large distances.

As U.S. and U.K. forces were investigating solutions to this issue, a similar problem had arisen for slightly different reasons in the various deployments in the former Republic of Yugoslavia. The provision of an area network had proven very difficult due to the inability to find secure sites for relays between widely dispersed units and formations.

The solution to both of these problems has been the introduction of satellite trunk links to extend the range of connections between nodal, which does not affect the logical layout of the area network, but dramatically increases the range of internodal links. As illustrated in Figure 4.11, area networks are provided locally where possible and satellite links are provided to link these network “enclaves” or “islands” together.

#### *4.4.2.2.4 Commercial Communications Networks*

In addition to satellite links, connections between nodes can also be extended by connections through commercial communications networks. However, commercial systems are not always available or survivable enough

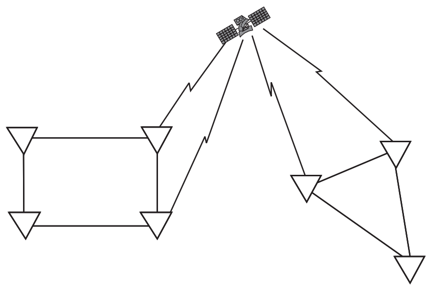

**Figure 4.11** A simple area network architecture employing satellite internodal links.

for inclusion in trunk networks. Satellite trunk links are therefore preferred to span large distances between nodes.

#### 4.4.2.3 Access Nodes

An *access node* is a processor-controlled digital switch capable of handling the number of fixed subscribers at the access point. The access node can switch calls between these subscribers or switch them to an outgoing trunk line through the trunk switch. Normally, two levels of access nodes are provided: a small access node for brigade headquarters and a large access node for divisional headquarters. In some networks, access nodes are provided down to lower levels to serve subscribers at regimental or battalion command posts. In most networks, however, access to these levels is provided through SCRA, because the users are mobile and fixed subscriber access to the network tends to be inappropriate. As illustrated in Figure 4.12, subscribers are connected to the access node, which is connected to the network (to a trunk node) through radio-relay bearers. Large access nodes (for divisional headquarters and above) are normally connected to two trunk nodes; small access nodes (for brigade headquarters and below) are normally only connected to one trunk node, with a standby link engineered to a second trunk node in case of failure of the first.

Small access nodes normally serve approximately 25 subscribers and the large access nodes provide for approximately 150 subscribers. As well as the ability to interface to radio-relay bearers, both types of nodes have the facilities to interconnect to satellite or troposcatter links, or to commercial carriers. Figure 4.13 shows a simplified layout of a small access node.

As illustrated in Figure 4.14, the large access node has a similar layout as the small node. In addition to the ability to cope with a larger number of subscribers, the large access node is connected to two trunk nodes. The large

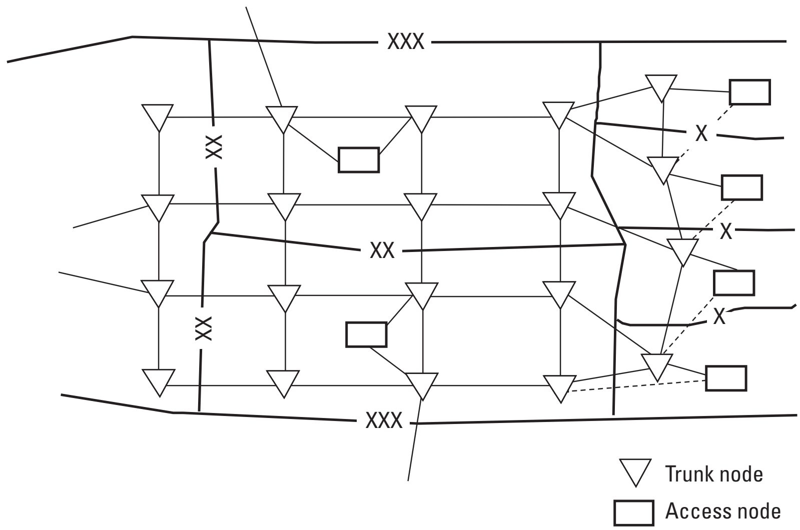


**Figure 4.12** Connection of access nodes to the trunk network.

access node also contains an NOC and an NMF, similar to those found in the node center of a trunk node.

#### 4.4.2.4 SCRA

Access nodes provide access for fixed network subscribers. Access for mobile or isolated subscribers is provided through the duplex VHF-radio access of the SCRA subsystem. The SCRA subsystem comprises *subscriber terminals* that provide mobile users with network facilities (e.g., voice, data, telegraph, and facsimile) equivalent to those available to static subscribers of an access node, and RAP through which subscribers access the trunk network. As illustrated in Figure 4.15, an RAP is normally connected to the network by connecting to a trunk node via cable, SHF down-the-hill radio, or UHF radio-relay link. A standby link is engineered to another trunk node to be used if the primary link fails. RAPs are deployed like PCS base stations to provide overlapping areas of coverage to provide continuous coverage for a mobile user.

*RAPs.* In most in-service networks, each RAP can accommodate approximately 50 affiliated mobile subscribers (i.e., 50 subscribers who are within the RAP's operating area). Not all affiliated subscribers can communicate at once, however, and an RAP can normally only cope with simultaneous calls from a dozen subscribers. While the RAP will have a planning range of 15 km,

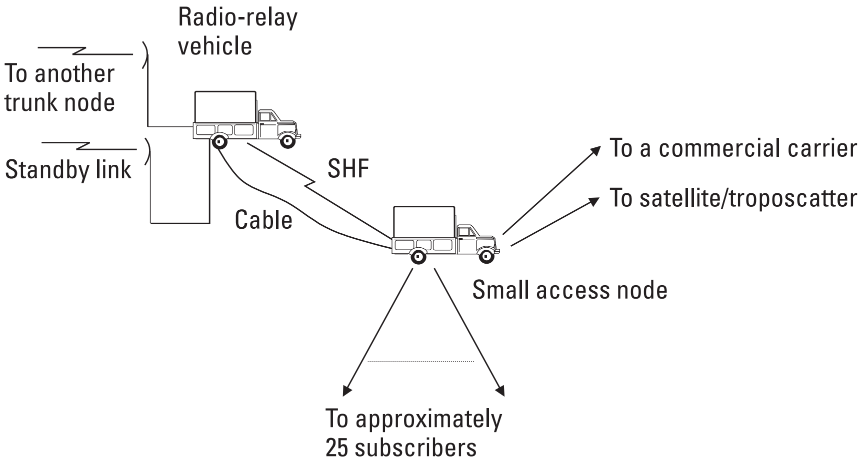


**Figure 4.13** Simplified layout of a small access node.

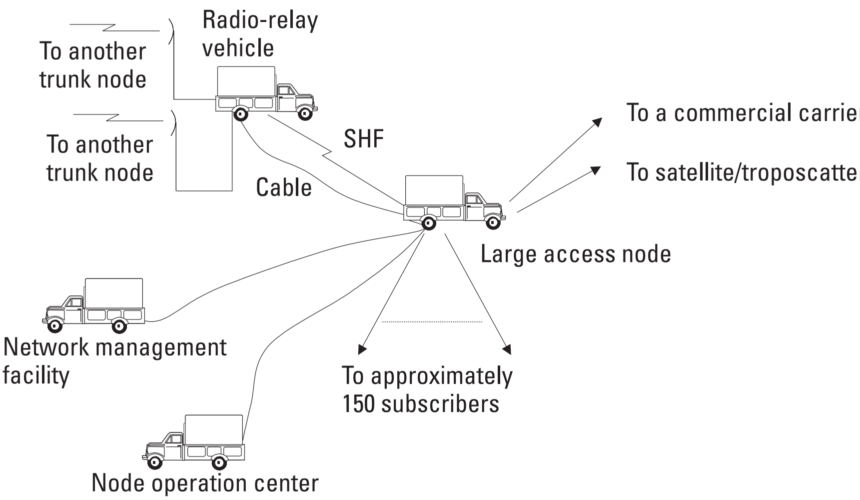


**Figure 4.14** Simplified layout of a large access node.

the actual range between the RAP and subscriber will depend on the terrain and the heights of the RAP and mobile antenna. Figure 4.16 shows a simplified layout of an RAP site, which comprises an RAP vehicle containing transmitters and receivers connected to an omnidirectional antenna. RAPs

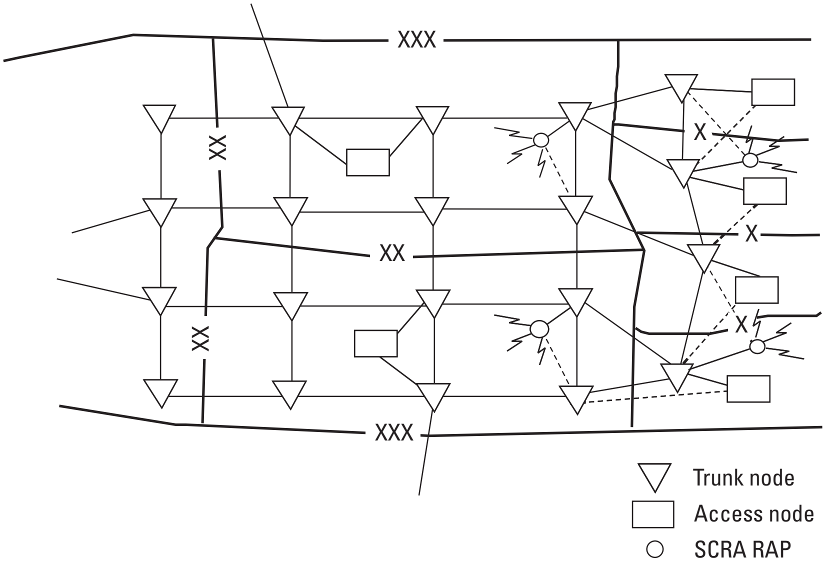


**Figure 4.15** Connection of SCRA RAPs to the trunk network.

are normally able to operate on a range of power settings so that the lowest power level can be chosen for each user to reduce the electronic signature of the RAP.

*Subscriber terminals.* To connect to the network, a mobile subscriber is required to go through a process of *affiliation*, during which the subscriber's identity is validated. Each network conducts its affiliation process slightly differently, but normally the subscriber is required to perform some deliberate action to affiliate for the first time. In some networks the subscriber must continue to affiliate each time connection is required to a new RAP. If the subscriber does not know the number of the closest RAP, a search can be initiated to find the most suitable RAP. In more modern networks, reaffiliation is automatic as the subscriber is handed over from one RAP to another while moving through the network. Upon affiliation, the power output of the terminal is normally reduced to the minimum possible power level to ensure similar power levels at the RAP from all subscribers, and to reduce adjacent channel interference

*Direct access.* In the more modern networks, mobile subscribers in close proximity within the same RAP area do not have to communicate through

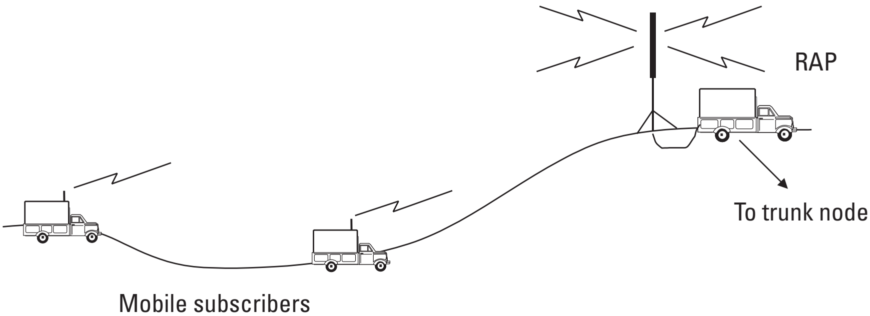


**Figure 4.16** Simplified layout of an RAP.

the RAP and can contact each other directly. This not only reduces traffic load on the RAP, which is only used to relay the call if the direct connection cannot be made within a specified time, but it allows communications when the network is not present.

#### 4.4.2.5 CNRI

SCRA is an extension of the trunk network in that subscribers have access to the same network facilities as static subscribers in command posts. In addition to SCRA, most networks provide an additional form of access to lower-level commanders who are not network subscribers but who can use their CNRs to have temporary access to the network. This CNRI provides a semi-automatic, voice interface between VHF and HF CNR users and the network. The range of CNRI depends on the CNR frequency band. In each frequency band, the CNRI vehicle has a hailing channel through which CNR users can contact the operator who sets up the call through one of the VHF or HF traffic radios. In the other direction, calls made from the network are automatic and do not require operator intervention. While it is possible for a CNR user to access the network in this way, CNR nets are single-frequency, half-duplex so that CNRI only provides rudimentary access to network facilities. RATEL and CNR net procedures must be observed by CNRI users, even those who are trunk subscribers.

#### 4.4.2.6 Tactical Interface Installations

For NATO in Western Europe during the Cold War, it was important that each corps was able to provide communications to flanking formations from other nations. While the Cold War deployments are less likely, multinational alliances are essential in almost all modern deployments and it is perhaps even more important for modern networks to be able to interface to those of other nations. There are therefore a large number of standards and agreements that cover the interface of trunk networks. For example, within NATO, the internetwork interface for analog signals, voice, and telegraph is arranged through the standard agreement STANAG 5040 [12], and interoperability between digital EUROCOM [13] systems using 16-Kbps modulation is provided by STANAG 4208 [14]. It is unlikely, however, that national procurement programs will ever be completely synchronized and most networks arrange to support the interface through a specific installation called the TII.

### 4.4.3 Trunk Subscriber Facilities

Traditionally, trunk networks provide static and mobile subscribers with secure voice, data, telegraph, and facsimile services. In the future, these services might also include video. The following gives a brief overview of the equipment and facilities provided to subscribers in most current networks.

*Subscriber equipment.* Subscribers make voice calls through the digital circuit-switched network using a digital or analog telephone. Data, facsimile, and telegraph facilities are provided through the attachment of a *data adaptor*. The subscriber equipment performs analog-to-digital conversion to provide an output data rate, normally at 16 Kbps using a form of delta modulation.

*Security.* Trunk network security is provided through bulk encryption of the trunk links so that the network is normally treated as a SECRET-high network. That is, it is assumed that any subscriber at any point in the network is cleared at least to the SECRET level, and that there are physical security measures in place to ensure that only appropriately cleared personnel can receive the information. If higher classifications are desired, links between users can be individually encrypted once a circuit has been established. This form of double encryption is commonly used for intelligence and electronic warfare users.

*Voice services.* Subscribers can move about within the network and may not necessarily remain near the same subscriber equipment all the time. Most modern networks therefore give each subscriber a unique number called a *directory number* that they can enter on any phone in the network to tell the network where they can be found so that a call can be placed to them. A subscriber can be located at any time through *affiliation* and *flood search*. It does not make sense to have to issue a phone directory for an organization whose staff is changing constantly, so most networks also use the NATO 7-digit deducible directory (STANAG 5046 [15]), in which the subscriber's directory number is deducible from the parent unit and appointment. Trunk networks provide the normal network voice facilities such as call waiting, transfer, and call forward, along with the more modern facilities of compressed dialing, abbreviated dialing, and conference facilities. Particular military requirements are met by the *precedence* and *preemption* facilities. Preemption allows selected subscribers to manually override other callers for access to outgoing trunks (or if the called extension is busy), providing the caller's precedence is greater than that of the subscribers involved in the busy conversation.

*Affiliation.* Subscribers are free to access the network from any point where there is a subscriber terminal. To do so, however, the network must know where each subscriber is located so that incoming calls can be routed to the correct location. Each subscriber is therefore required to affiliate to the network by entering an affiliation sequence into the nearby terminal, which tells the local switch where the subscriber is currently located.

*Flood search.* When a call is placed, the subscriber is located by the network through a flood-search mechanism in which the switch to which the calling subscriber is connected calls all other switches until the called subscriber's parent switch responds. Once the subscriber's location has been identified, the connection can be made.

*Data services.* Data services can be provided by a number of methods, but are normally provided by a packet-switched network integrated into the circuit-switched network. Chapter 6 provides more detailed discussion on the provision of voice and data services across modern networks. In current networks, however, there are two main methods available to integrate circuit and packet switching within the same trunk network:

- *Common trunking.* The most obvious approach is through common trunking, where the circuit and packet switches share the common transmission facilities via multiplexing equipment. However, integration at this level does not really provide much for improvement in transmission efficiency and utilization, or the exchange of traffic between different communities or terminal types.

- *Embedded network*. In most modern networks, the packet-switched network is embedded in the circuit-switched network. Each switch still has its own community of users, but the packet switches act as user terminals within the circuit-switched network. Using the connections through the circuit-switched network as bearers, each packet switch connects to others to form the packet-switched network. The allocation of trunk channels to the packet-switched network is normally predetermined, although many networks allow the allocation of additional capacity, should the amount of traffic between any pair of packet switches begin to increase.

### 4.4.4 Network Management

As trunk networks have matured and have become more independent of the chain of command, network management has also had to evolve as a separate function. As networks have become more complex, the management task has become an indispensable component of modern networks.

#### 4.4.4.1 The Management Task

The principal role of network management is to ensure that the network provides and maintains effective and reliable communications. A number of management tasks must be conducted: assessment of the requirement, including identification of subscriber communities for voice, data, SCRA, and CNRI; formulation of a plan for network connectivity, including the radio path planning for bearers; planning for the location of key network elements such as radio-relay detachments and RAPs; allocation of resources to meet the plan; preparation and issue of orders; assignment of frequencies; management of changes to the network, both planned and unexpected; system performance analysis; traffic engineering; cryptographic management; system maintenance; and implementation of EP plans.

The impact of the role of network management cannot be understated. Although modern area networks are inherently flexible, they can only remain so if they are well managed. The network must redeploy, and key network elements will be moving, or may even be destroyed. The continual configuration and reconfiguration of the network must be tightly controlled if the network is to remain available to users. The trunk communications system is a critical element of the commander's combat capability and must be able to withstand the demands of the tactical environment. While the meshed area network provides great flexibility, it also introduces a significant overhead in terms of network management.

#### 4.4.4.2 Functional Levels of Management

The evolution of tactical communications systems has seen a disassociation of communications elements from the units and formations they support. Similarly, it is not common for network management elements to have a close affiliation with formations. In a modern area network, the management structure is centralized to ensure the optimum usage of system resources and the provision of maximum availability to users. That does not mean to say, however, that there is not a hierarchy of management. Rather, there are a number of functional levels of management and management elements are normally associated with logical, geographical groupings of network assets to provide the redundancy necessary for a survivable management system. The number and the nature of functional levels of management will depend to a large degree on the type of trunk network employed.

### 4.4.5 SDS

The SDS is a service provided by specialist signal units or logistics units to physically carry messages from one location to another on the battlefield. Much of the information that needs to be transferred between headquarters would take far too long to transmit over the sparse bandwidth available in tactical communications systems. Other information is of relatively low priority and can be passed by hand, releasing communications links for more urgent traffic. Messengers can be mounted in vehicles or on motorcycles or may make use of permanently allocated aircraft on permanent allocation or other aircraft when available.

Compared to other trunk bearers, the main advantages of SDS are that it has an enormous capacity when compared to radio bearers, is relatively easy to secure as it is vulnerable only to physical threats, and is error-free (barring accidents, of course). Unfortunately, messenger services require considerable staff numbers, can take some time compared to radio transmissions, and can lack control while the messenger is in transit.

## 4.5 Principles of Military Communications

The doctrine of most modern armies contains a number of principles for the provision of tactical communications. These principles have been developed over many years to provide guidance for the provision of tactical communications systems to support land operations. While each principle articulates an important factor, it is rare that any one principle can be pursued vigorously without detriment to some other, and some compromise must generally be met.

*Communications support the chain of command.* Tactical communications systems are essential elements of a command system. The communications system must facilitate the chain of command and not constrain the ability of commanders and staffs to implement the C2 cycle. Similarly a commander's tactical plans must not be constrained by the range and capability of supporting communications systems.

*Integration.* A tactical communications system comprises a number of subsystems that must be integrated together efficiently. The provision of communications must therefore be controlled at the highest level of the deployed force, through the use of an integrated network management structure that supports the chain of command and can exercise tactical and technical control over the whole communications system.

*Reliability.* Reliability is a critical property of tactical communications systems since commanders are so heavily reliant on them and their loss is likely to cause significant tactical disadvantage. Reliability is so important on the battlefield that commanders often prefer equipment that is less capable but more reliable since it is generally much better to have a simple system that can be depended on than a sophisticated one that fails at critical points. Good planning, employment of equipment with a high mean-time-between-failure, and high standards of training reduce the risk of breakdown and increase the reliability of communications systems. System availability can also be increased by providing redundancy through the use of both standby equipments and alternative systems.

*Simplicity.* As tactical communications systems become more complicated and sophisticated, communications planners must resist the temptation to have equally complex plans. A simple plan is more likely to be flexible and to survive the stresses and strains placed on the network by the tactical environment. Communications equipment should also be easy to operate and simple to repair.

*Capacity.* A communications system must be able to cope with traffic peaks and permit all communications within the desired time frame and priorities. However, communications capacity will always be a scarce resource on the modern battlefield and measures must be devised to regulate the use of communications systems. There are three aspects of the provision of a tactical communications network with sufficient capacity: sufficient capacity of individual bearers, adequate coverage, and adequate access.

*Quality.* There are considerable differences in the requirements for quality (including accuracy) between the military and commercial user. At one extreme, the military user will accept intelligible voice, whereas most commercial telephone systems provide a high quality of reproduction with a very good level of speaker recognition. At the other extreme, while the requirements for errorless data transmission from terminal to terminal are the same in both environments, the commercial expectation of high-quality transmission media (error rates of certainly less than 1 in 10 [5]) may be unacceptably high in the military. This leads to difficulties when adopting commercial standards. Modern communications standards have generally been developed for transmission media such as fiber optic cables, which expect that few or no errors are introduced during transmission. Adoption of commercial data communications protocols within military networks therefore tends to require that additional error detection and correction is incorporated into the standard or especially provided by tactical communications protocols.

*Flexibility.* Tactical communications systems must be able to adapt quickly to any changes in the tactical environment and to continue to provide communications coverage as the deployed force maneuvers. Additionally, the same communications equipment must be able to be used for as many military tasks as possible. Equipment must therefore be flexible in the way it is deployed to meet the wide variety of tactical circumstances, as well as being able to carry different sorts of traffic such as voice, data, telegraph, and video. It is unlikely that any single communications equipment can provide all the needs of all users in all tactical situations. A communications system is flexible by providing a mix of equipment and combining the strengths of each. The main factors in the provision of flexible networks are: good planning, alternative routing, reserve equipment, personnel, and capacity on circuits, good standing operating procedures (SOP) and drills, and a high standard of training to reduce planning and deployment times.

*Anticipation of requirements.* The requirement for flexibility can be mitigated in some regard by anticipating the requirements of the deployed force. Commanders must therefore ensure that communications staff are kept informed throughout the C2 cycle, so that communications infrastructure can be deployed in anticipation of future plans.

*Mobility.* At all levels, the mobility of communications equipment must meet that of the user. For combat troops this means that radio sets must be portable or able to be fitted into fighting vehicles. For headquarters, a communications network should be able to cope with a considerable degree of movement by combat elements without needing to redeploy. The communications system must also allow commanders to command and control on the move (previously, commanders have been required to step up headquarters to achieve continuity of command). However, when required to move, the components of a communications system must have the ability to change location as rapidly as the combat elements that they serve.

*Security.* Due to its crucial role in support of the C2 cycle, the tactical communications network will be a prime target of adversary intelligence gathering. Protection of the information carried by the tactical communications system is therefore of prime importance. Security is a major factor in the provision of an adequate tactical communications system, and a comprehensive security architecture must be developed to provide guidance to the development of a communications architecture. There are three aspects of a secure network: physical security, personnel security, and electronic security (encryption as well as transmission and emission security).

*Economy.* In the commercial environment, the provision of fixed infrastructure means that there is ample bandwidth available to meet the requirements of all users. On the battlefield, communications resources will always be scarce because of the high cost of the resources themselves, as well as the personnel and materials needed to establish, operate, and maintain them. For example, while the provision of sufficient bandwidth is not generally a problem in the commercial and fixed environments, bandwidth will always be a scarce resource on the modern battlefield [16]. Communications systems must therefore be used economically and users must accept that facilities will invariably have to be shared. To maintain the principle of economy, users must ensure that: the appropriate means of communications are utilized, demands for communications are kept to a minimum, sole-user facilities are demanded only when absolutely necessary, plans are based on a realizable scale of communications, and contingency plans are available to accommodate operations if communications are disrupted for any period of time. Economy also requires individual communications equipment to be spectrally efficient to maximize the usage of limited spectrum.

*Survivability.* The modern battlefield represents a harsh electromagnetic environment within which the tactical communications system must survive. A communications system is survivable if it has: sufficient capacity to handle traffic levels, an ability to manage existing capability through techniques such as dynamic bandwidth management, the necessary levels of security, low probability of intercept, resistance to jamming and interference, mobility, alternative routing, alternative means, redundancy, and sufficient reserves.

*Interoperability.* The systems and networks within the tactical communications system must be interoperable with other tactical networks, strategic networks, unclassified commercial networks, as well as networks and systems of other services and allies. This interoperability is essential if information is to be able to flow seamlessly between any two points in the battlespace, and between any point in the battlespace and the strategic communications system. Additionally, new equipment will invariably need to interoperate (be backwards compatible) with current in-service equipment.

## 4.6 Summary

In almost all modern armies, the tactical communications system has evolved to comprise two major components: the trunk communications subsystem and the CNR subsystem. The trunk communications subsystem provides high-capacity links (terrestrial radio relay, satellite, fiber optic, or line) that interconnect headquarters at brigade level and above. The network is provided by a number of trunk nodes interconnected by trunk links to form a meshed area network. Access is normally gained through access nodes that connect to one or more trunk nodes. Voice, telegraph, data, facsimile, and video facilities are provided to staff officers and commanders. The CNR subsystem is a ruggedized, portable radio network carried as an organic communications system for combat troops (brigade level and below). Radios are invariably interconnected to form single-frequency, half-duplex, all-informed, hierarchical nets, providing commanders with effective support to command and control. In U.S. doctrine, a third subsystem, the ADDS, is provided—the utility of this third element is discussed in Chapter 5.

These subsystems have developed over time to meet the particular needs of battlefield commanders. Similarly, doctrine has evolved to articulate a number of principles of military communications. It is essential that this background is used as a starting point for an analysis of a suitable architecture for future tactical communications. While the Information Age has the promise to revolutionize warfare, it is not likely to obviate the requirement for every element of the current tactical communications system, nor invalidate all of the extant principles for military communication. Cognizant of this background, therefore, Chapter 5 conducts an appreciation of the communications support required to support tactical commanders on the digitized battlefield.

## Endnotes

[1] Further details on the history of military communications can be found in the following:

Harfield, A., *The Heliograph*, Royal Signals Museum, Blandford Camp, U.K., 1986.

Nalder, R., *The History of British Army Signals in the Second World War*, London: Royal Signals Institution, U.K., 1953.

Nalder, R., *The Royal Corps of Signals*, London: Royal Signals Institution, U.K., 1958.

Royal Signals Institution, *Through to 1970*, London: Royal Signals Institution, 1970.

Scheips, P., *Military Signal Communications*, *Vol. 1,* New York: Arno Press, 1980.

Scheips, P., *Military Signal Communications*, *Vol. 2*, New York: Arno Press, 1980.

[2] Further details on the use of animals in military communications systems can be found in the following:

Harfield, A., *Pigeon to Packhorse*, Chippenham, U.K.: Picton Publishing Ltd, 1989.

Osman, A., and H. Osman, *Pigeons in Two World Wars*, The Racing Pigeon Publishing Co. Ltd., London, 1976.

[3] There has been some interesting use of pigeons in more recent times—the Swiss Army only decommissioned their pigeons in 1994, and Major General John Norton, commander of the 1st U.S. Air Cavalry, initiated a small (abortive) communications experiment to revive use of carrier pigeons during the Vietnam War (see Meyer, C., *Division Level Communications*, Department of the Army, Washington, D.C., 1982, p. 45).

[4] For more details, see Wilson, G., *The Old Telegraphs*, London: Phillimore & Co. Ltd., 1976.

[5] The use of heliograph, signaling lamps, and signaling flags provided early commanders with useful systems for extending communications ranges. They quickly lost favor on the static battlefield of World War I, as the operator had to be exposed to obtain any reasonable ranges and they have not been used since in battlefield communications systems. It should be noted, however, that each of these forms of communications persist

in modern navies, where they are very useful for low-capacity line-of-sight communications links when the operational environment requires radio silence.

[6] FM 24-18, *Tactical Single-channel Radio Communications Techniques*, Washington, D.C.: Headquarters Department of the Army, Sept. 30, 1987.

[7] Further details on in-service CNR can be found in the following:

*Jane's C4I Systems*, *2000-2001*, Surrey, England: Jane's Information Group, 2000.

*Jane's Military Communications Systems, 2000–2001*, Surrey, England: Jane's Information Group, 2000.

Witt, M., "Tactical Radios: A Never-Ending Saga," *Military Technology*, July 1999, pp. 22–32.

[8] Ryan M., *Battlefield Command Systems*, London: Brassey's, 2000, p. 139.

[9] Further information on trunk networks can be found in the following:

Blair, W., and S. Egan, "A Common Approach to Switching in Tactical Trunk Communications Systems," *Journal of Battlefield Technology*, Vol. 4, No. 2, pp. 17–21.

Hewish, M., "Tactical Area Communications Part 1: European Systems," *International Defense Review*, Vol. 5, 1990, pp. 523–526.

Hewish, M., "Tactical Area Communications Part 2: Non-European Systems," *International Defense Review*, Vol. 6, 1990, pp. 675–678.

*Jane's C4I Systems, 2000–2001*, Surrey, England: Jane's Information Group, 2000.

*Jane's Military Communications Systems, 2000–2001*, Surrey, England: Jane's Information Group, 2000.

[10] Meyer, C., *Division-Level Communications 1962–1973*, Department of the Army: Washington, D.C., 1982, p. 7.

[11] *The U.S. Army Signal Corps in Operation Desert Shield/Desert Storm*, U.S. Army Signal Center Historical Monograph Series, Office of the Command Historian, United States Army Signal Center and Fort Gordon: Fort Gordon, Georgia, 1994, p. 4.

[12] STANAG 5040, *NATO Automatic and Semi-Automatic Interfaces Between the National Switched Telecommunications Systems of the Combat Zone and Between these Systems and the NATO Integrated Communications System (NICS)–Period From 1979 to the 1990s*, NATO, Brussels, Oct. 23, 1985.

[13] EUROCOM D/1 Standard, *Tactical Communications Systems—Basic Parameters*, NATO, Brussels, 1986.

[14] STANAG 4208, *The NATO Multi-Channel Tactical Digital Gateway—Signalling Standards*, NATO, Brussels, Nov. 15, 1993.

[15] STANAG 5046, *The NATO Military Communications Directory System*, NATO, Brussels, Aug. 8, 1995.

[16] As described in Chapter 5, this bandwidth paucity on the battlefield is mainly caused by the limitations of the physics associated with the methods of propagation available to tactical communications systems.