FREEING MERCURY'S WINGS

Improving Tactical Communications in Cities

Sean J. A. Edwards

Arroyo Center
RAND

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PREFACE

The objective of this monograph is to highlight ways to improve command, control, and communications in military urban operations. In particular, this research should be of interest to those concerned about communication problems facing dismounted infantrymen in urban environments. The information cutoff date is September 17, 2000.

This research was conducted for a project on Military Operations on Urbanized Terrain, sponsored by the Assistant Secretary of the Army (Acquisition, Logistics, and Technology). It was carried out in the Force Development and Technology Program of RAND Arroyo Center, a federally funded research and development center sponsored by the United States Army.

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SUMMARY

As U.S. military forces modernize and rely more on information systems, the radios that transmit information will become more critical. Both technology and doctrine need to be adjusted to meet the increasing demand for bandwidth on the battlefield.

This analysis offers suggestions on how to improve command, control, and communications (C3) in urban environments, with a particular focus on wireless communication options. The most stressful scenario is assumed—that is, dismounted maneuver units at battalion and below echelons conducting combat operations.

The monograph first describes the current communications challenge, in terms of both the technical difficulties of using wireless communications in urban terrain and the operational requirements of warfighters today. It then summarizes current doctrine and suggests a few areas where tactics could be changed to help overcome communication problems. Finally, it examines current and future communication technologies.

Determining the information requirements of 21st-century soldiers is a complex problem that will continually evolve as the services conduct field experiments to test the impact of new technologies. Both engineers and users must work together to assess the value of new equipment, make the necessary tradeoffs (dropping current equipment to make room for the new), and possibly change existing tactics, techniques, and procedures (TTPs). A DoD program, the Military Operations on Urbanized Terrain (MOUT) Advanced Concept Technology Demonstration (ACTD), recently generated a set of information requirements and did a search for existing technological

solutions. The evaluators found that the most persistent problem is the difficulty in communicating through walls or into a building interior. The most intractable requirements were

- Position location inside buildings
- Detection of snipers
- Through-wall sensors
- Combat identification of friendly forces, enemies, and noncombatants.

KEY FINDINGS OF THIS REPORT

Because our ground forces are developing new operational concepts that rely on situational awareness, we need to consider ways to provide more reliable command, control, and communications. We should consider both doctrine and technology.

Doctrine

A quick read of current doctrine on communications in urban operations yields a limited amount of advice. In general, military manuals focus on site location, proper training, and other practical considerations such as cover and concealment and avoiding interference. Alternative means of communication—including wire, messengers, visual and sound signals, and using the existing commercial infrastructure—are usually mentioned. Field manuals should be updated with further lessons on how to overcome line-of-sight problems, fading, and path loss. It is time to prioritize the communication needs of battalion and company commanders and come up with new TTPs that minimize their vulnerability to loss of communications. Some general recommendations are offered below.

Leverage the urban terrain. As the U.S. Army continues to add more computers and radios to its vehicles and soldiers, commanders preparing for the urban fight should carefully consider urban terrain from a communications perspective. Soldiers can use high buildings as base stations or relays, leverage the civilian infrastructure when appropriate, and identify and avoid electromagnetic deadspace. One technique, known as "obstacle amplification," is to place transmitters in such a way as to enhance the signal strength in otherwise poorly covered areas by taking advantage of reflection from buildings or other surfaces.

Plan the scheme of maneuver. In general, a commander can plan his scheme of maneuver with radio propagation as a primary consideration. Fire and movement TTPs can be changed for crossing deadspace and then changed back to standing procedures once the special areas are traversed. Deadspace can be avoided or isolated.

Recognize zones of situational awareness. In zones where situational awareness is severely limited, such as sewers, subway systems, underground weapons of mass destruction (WMD) facilities, and other subterranean structures, alternate TTPs may be necessary. It may make sense for a commander to train his troops to use a second set of tactics when fighting within these zones or to use specialized troops. One example where C3 TTPs might differ is between-building areas and within-building areas.

Change coordination mechanisms. Organizational theory can offer insights into how to reduce the need for communication within an organization. Using other coordination mechanisms besides direct supervision, a commander can reduce the need for explicit communication both vertically (up and down the chain of command) and horizontally (between units at the same echelon) within his unit.

Communication Technologies

In terms of technology, there are no "silver bullets," but several technologies do appear to promise incremental improvement.

In the near term (0–3 years), current and emerging very-high-frequency (VHF) and ultra-high-frequency (UHF) radios are still the best option for the dismounted infantryman. Most tactical military radios that are small and light enough to be carried by a soldier are in the VHF and UHF frequency bands. The single-channel ground and airborne radio system (SINCGARS) is the baseline radio for U.S. forces.

The Army and the Marine Corps believe that commercial-off-the-shelf (COTS) radios can help at the squad and fire team levels. Field experiments show that equipping every leader down to the fire team level with a short-range radio has a tremendous impact at the company level and below, greatly increasing situational awareness. Adding intra-squad radios (ISRs) allows infantrymen to avoid "stacking" and bunching before entering buildings, increases dispersion in general, and reduces fratricide. Coordination both among and between squads has increased. Tank/infantry coordination is now possible at the fire team level, since tanks and armored vehicles can also use ISRs. After extensive testing, the Marine Corps has chosen a UHF commercial voice radio system as a candidate for its future intra-squad radio.

MOUT ACTD evaluators are also looking at commercial short-range radios for squad members. Because the MOUT ACTD is ongoing, its evaluation is not complete at the time of this writing, but preliminary field tests indicate that UHF commercial radios are the best choice for intra-squad communications.

Cellular and satellite telephones are not ideal for urban combat for a number of reasons:

- They require a fixed infrastructure of base stations and land lines, which can be vulnerable during military operations.
- They do not have high data rates.
- They are incompatible to some degree with existing military systems.
- They have poor security and are easily jammed.

With the above limitations in mind, these devices may nonetheless be useful in some cases, particularly in urban operations that occur during support and stability missions. Enemy jamming and physical destruction of base stations may not occur in more benign missions such as peacekeeping. As a result, the services remain interested in supplementing planned military systems with some cellular or satellite phone systems. Marine Corps evaluators favored the Multiple Path Beyond Line of Sight Communications (MUBLECOM) low-earth-orbit system.

Unmanned aerial vehicle (UAV) relays can shorten link distance and overcome noise and line-of-sight (LOS) problems for units positioned outside buildings in the urban canyon. Given that UAVs are still relatively complex machines that require skilled technicians and extensive ground-based support, this option will probably not be practical for several years.

Man-portable relays can also overcome breaks in LOS between transmitters and receivers. Attritable relays are carried by individual soldiers and hand-emplaced as the tactical need arises in the field. DARPA is working on an attritable relay with three versions that act either as routers, repeaters, or geolocation beacons. The short lifespan and easily compromised security of these devices probably limits their usefulness to surgical missions, such as seizing and controlling the interior of a single large building.

In the middle or far term (3–10 years), communication problems such as fading may be countered to some extent by the maturation of several technologies, including software radios, ultra-wideband (UWB) waveforms, array antennas, and UAV relays.

New software radios use software applications to perform some of the major communications functions that analog or hardware components do in current radios. These radios are capable of optimizing modulation, frequency, and power level to maximize performance in restrictive environments. DARPA is developing a software radio called the Individual Warfighter Situational Awareness System (IWSAS). DARPA R&D plans call for an IWSAS prototype test in late FY01 and field demonstrations and final reports by June 2002.

Other promising technologies include ultra-wideband signaling and array antennas. Ultra-wideband signaling is a new signaling technique that is covert, jam resistant, and more resistant to multipath fading. Directional antennas also reduce multipath fading. Because directional antennas must have dimensions that are larger than a wavelength, building a hand-held or man-portable VHF and UHF array antenna is impractical. However, man-portable array antennas are possible for higher frequencies such as SATCOM and commercial cellular.

UAV communication relays may be practical in the middle or far term. DARPA is running a program called Airborne Communications Node (ACN) that is developing communication payloads for UAVs. These payloads will be scalable and modular, so they may be reduced in size down to 25 pounds, small enough to fit on a tactical UAV like the Shadow. ACN will support VHF and UHF combat net radios as well as the higher-frequency S- and Ku-band SATCOM radios. By FY03, DARPA plans to deliver a "critical design," which the services could theoretically use to build a vehicle. Production and/or further testing could occur by FY05.

A FINAL NOTE

Plans to field a digitized ground force in the near future will place a premium on reliable wireless communications. The fact that current doctrine on overcoming communication problems is so meager casts a cold light on the question of whether new and innovative ways can be found to meet the warfighter's needs. Updating field manuals with some of the lessons that commercial engineers have learned is a useful start.

One should remember, though, that communication problems have always existed and will continue to do so, not only because of the physical nature of urban terrain but also because of the chaotic nature of war. In combat, antennas are shot off, radios are damaged by explosions, and radio operators are killed by snipers. Soldiers must constantly adapt to changing levels of situational awareness. No matter how many new technologies they carry, soldiers and marines will always need to train with a baseline set of command and control TTPs that work in the absence of wireless communications.

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ABBREVIATIONS

ACTD	Advanced Concept Technology Demonstration
A/D Converter	Analog-to-Digital converter
AJ	Anti-jam
ASIC	Application-Specific Integrated Circuit
ASIP	Advanced System Improvement Program
AWE	Advanced Warfighting Experiment
BER	Bit Error Rate
bps	Bits per second
CAS	Close Air Support
CECOM	Communications-Electronics Command (Army)
CINC	Commander in Chief
CONUS	Continental United States
COTS	Commercial Off the Shelf
CPE	Culminating Phase Experiment
C2	Command and Control
C3	Command, Control, and Communications
C4	Command, Control, Communications, and Computers

C4ISR	Command, Control, Communications, and Computers, Intelligence, Surveillance, and Reconnaissance
DARPA	Defense Advanced Research Projects Agency
dB	Decibels
DBBL	Dismounted Battlespace Battle Lab
DF	Direction Finding
DISA	Defense Information Systems Agency
DoD	Department of Defense
DSP	Digital Signal Processor
ECCM	Electronic Counter Counter Measures
ELB	Extending the Littoral Battlespace
EO	Electro Optical
FBCB2	Force Battle Command Brigade and Below
FLOT	Forward Line Of Troops
FPGA	Field-Programmable Gate Array
FXXILW	Force XXI Land Warrior
GAO	General Accounting Office
GHz	Gigahertz
GPS	Global Positioning System
HF	High Frequency
Hz	Hertz
IDF	Israeli Defense Force
IPB	Intelligence Preparation of the Battlefield/Battlespace
IR	Infrared
ISI	Intersymbol Interference
ISR	Intra-Squad Radio

ISR	Intelligence, Surveillance, and Reconnaissance
IWSAS	Individual Warfighter Situational Awareness System
JITC	Joint Interoperability Test Command
JTA	Joint Technical Architecture
JTF	Joint Task Force
JTR	Joint Tactical Radio
JWSTP	Joint Warfighting Science and Technology Plan
Kbps	Kilobits per second
KHz	Kilohertz
LOS	Line of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LW	Land Warrior
MBITR	Multiband Inter/Intra Team Radio
Mbps	Megabits per second
MCWL	Marine Corps Warfighting Lab
MHz	Megahertz
MOUT	Military Operations on Urbanized Terrain
MSHR	Miniature Secure Hand-Held Radio
MTR	Marine Tactical Radio
MUBLECOM	Multiple Path Beyond Line of Sight Communications
NASA	National Aeronautics and Space Administration
OMFTS	Operational Maneuver from the Sea
PMCS	Programmable Modular Communications System
R&D	Research and Development

RF	Radio Frequency
ROE	Rules of Engagement
RPV	Remotely Piloted Vehicle
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SA	Situational Awareness
SAR	Search and Air Rescue
SAS	Situational Awareness System
S&T	Science and Technology
SINCGARS	Single-Channel Ground Air Radio System
SNR	Signal-to-Noise Ratio
SOP	Standing Operating Procedure
STOM	Ship to Objective Maneuver
SUO	Small Unit Operations
THHR	Tactical Hand-Held Radio
TRADOC	Training and Doctrine Command
TRAC	TRADOC Analysis Center
TTP	Tactics, Techniques, and Procedures
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UHF	Ultra High Frequency
USMC	United States Marine Corps
UWB	Ultra-Wideband
VHF	Very High Frequency
VTOL	Vertical Takeoff and Landing
WDM	Wavelength Division Multiplexing

Chapter One

INTRODUCTION

> The American way of war is flying at 30,000-plus feet with some high-dazzle, whiz-bang thing that only kills bad guys; no Americans lose, fighter pilot comes home, lands at bar, has beer with beautiful girl. That's the American way of war. Well, a fight in the city is a bunch of 18-year-old kids going at it with knives and grenades, rifles and shotguns, stabbing each other in the stomach and blowing each other apart. It's a very, very ugly thing.
>
> —Colonel Rich Dunn[1]

Military urban operations are probably the most difficult type of operation that U.S. ground forces must perform today. Both the physical characteristics of urban terrain and the presence of noncombatants interfere with the traditional American approach to war, which is to apply massive amounts of firepower to destroy opposing forces and minimize friendly and noncombatant casualties.[2] At the lowest tactical levels, where infantrymen must fight and coordinate with each other while moving through back alleys and buildings, communication can be very difficult. Buildings and structures im-

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[1]Quoted in Sean D. Naylor, "A Lack of City Smarts? War Game Shows Future Army Unprepared for Urban Fighting," *Army Times*, May 11, 1998.

[2]In urban areas, the presence of noncombatants and the media can restrict the use of firepower because of U.S. political concerns over civilian casualties and collateral damage. Stringent rules of engagement (ROE) can prohibit or limit the effectiveness of tanks, artillery, and airpower. These self-imposed political constraints on the use of force encourage our enemies to fight on urban terrain in order to "even" the odds by forcing infantry-versus-infantry battles. Hypothetical adversaries in high-level wargames are already exploring the advantage of using this kind of "asymmetric" strategy. In recent Army After Next wargames, Red military forces consistently sought to use urban terrain to fight Blue forces. See Naylor, "A Lack of City Smarts?" op. cit.

pede command, control, and communications (C3) because they absorb, reflect, or block transmitted signals. Since soldiers[3] cannot communicate through walls and other obstacles in many instances, they are unable to pinpoint their position or determine the position of the enemy.

The communication problem is exacerbated by a growing warfighter demand for information. According to official joint doctrine, our future warfighters will rely on "information superiority" to enable new operational concepts. To meet this demand, the U.S. Army is "digitizing"—applying digital information technologies to—all Army field units.[4] Radios and computers mounted in vehicles or carried by foot soldiers will allow warfighters to share unprecedented amounts of information. As Army and Marine Corps units begin to conduct more dispersed and nonlinear operations, their reliance on command, control, and communications as a force multiplier will grow.[5]

The amount of information a commander possesses can be a major determinant of success on the battlefield. Human runners, cavalry, hot air balloons, and aircraft are just a few examples of how warfighters have gathered information (or intelligence) in the past, but only recently have we acquired the ability to gather vast amounts of real-time information from ground-, air-, and space-based sensors. The ongoing information and communication revolutions in the commercial arena offer the defense establishment a chance to access that information, filter it, and transmit it to the warfighter. Supplying and

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[3]Throughout this report, the term "soldier" refers to any type of ground troop (for example, a Marine) who engages in land combat.

[4]This effort includes the application of information and communication technologies (drawn for the most part from the commercial sector) so that every dismounted soldier, vehicle, aircraft, weapon, and sensor on the battlefield can share information. The current goal is to have an entire division digitized by the end of 2000 and a corps by 2004. See *The Army Digitization Report 2000, Report on the Plan for Fielding the First Digitized Division and the First Digitized Corps,* Presented to the Committee on Armed Services, United States Senate, Second Session, 106th Congress, April 2000, found at the Army Digitization Office's Web site at *http://www.ado.army.mil.*

[5]Models and simulations have shown that when soldiers are connected to a communications network, combat effectiveness is increased, resulting in higher lethality and lower casualties. See *Tactical Battlefield Communications*, Defense Science Board Task Force, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, February 2000, p. 74.

moving all this information means that tactical communications will have to be improved.

The objective of this analysis is to highlight ways to improve command, control, and communications (C3) in military urban operations, with a particular focus on communications. The title of this monograph, *Freeing Mercury's Wings*, uses a metaphor based on Roman mythology. Mercury was the messenger of the gods, and he was usually depicted with wings on his feet. To "free Mercury's wings" is to speed and ensure communications. This can be accomplished by either increasing the "supply" of communications or by decreasing the "demand." Information supply can be increased through new or improved technologies. Information demand can be lowered by adjusting tactics, techniques, and procedures (TTPs). We should approach the problem from both ends if we are to solve the difficult problem of using wireless communications in urban environments.

Since urban warfare is often infantry intensive, a logical starting point for an analysis of tactical C3 is Army and Marine Corps dismounted forces at the small unit level.[6] The focus here also is on wireless communications rather than optimal network architectures and designs. Mobile networking technologies offer much promise for non-LOS communication, but it is outside the scope of this analysis to cover this important subject.[7]

One caveat is in order: any suggestions to change the C3 of a military force must bear in mind that these elements cannot be divorced from a host of other related factors. Strategy and tactics, organizational structure and manpower systems, training, discipline, and the social makeup of an army all impinge on command and are in turn

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[6]Because of time constraints, this research concentrated on the doctrine and technologies associated with regular Army and Marine Corps forces. Special forces, anti-terrorist units, and SWAT police units would offer a rich source of information for future research into tactics and technologies that overcome C3 problems.

[7]Network architecture is a fundamental issue that defines many aspects of communications systems design. Packet radio networks are one possible answer to non-LOS problems. For a discussion of commercial wireless network technologies and their potential military applications, see Phillip Feldman, *Emerging Commercial Mobile Wireless Technology and Standards: Suitable for the Army?* Santa Monica, CA: RAND, MR-960-A, 1998.

affected by it.[8] For example, organization is probably the most important factor related to command. It determines the number, position, and responsibilities of noncommissioned and commissioned officers, the size and relationships of subunits, and the flow of information. The need for command arises from, and varies with, the size, complexity, and differentiation of an army. Once a force of any size is subdivided into several subunits, the problem of assigning a specific mission to each, and ensuring proper coordination between all, becomes much more difficult. Command and control difficulties also grow with the power and range of subunits' weapons, the speed at which those units move, and the dispersion between them. The command requirements of the ancient Greek armies that maneuvered as a single massed phalanx of hoplites were comparatively simple compared to those of modern mechanized armies consisting of many mobile units dispersed over great distances.

OUTLINE OF THIS MONOGRAPH

The rest of the monograph is organized as follows. Chapter Two describes the current communications challenge in terms of both the technical difficulties of using wireless communications in urban terrain and the operational requirements of today's warfighters. It also offers a review of ongoing DoD programs that are looking into aspects of the C3 challenge. The chapter finishes with a summary of communication tips drawn from various doctrinal publications. Chapter Three looks at doctrinal solutions, technologies, and a combination of both that can be implemented now or in the next few years. Chapter Four assesses possible technologies available after 2004. Chapter Five consists of concluding remarks.

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[8]Martin van Creveld, *Command in War,* Cambridge, MA: Harvard University Press, 1985, p. 261.

Chapter Two

WHERE WE ARE TODAY

TECHNICAL HURDLES

The "holy grail" of military communications is a mobile mesh communications network that shares voice and digital data between dispersed units and establishes situational awareness (SA), even in very restrictive terrain such as urban canyons or inside buildings.[1] This goal will probably remain elusive, given the pessimistic outlook of the joint community that "non-line-of-sight transmission through obstacles does not exist, nor does a breakthrough appear imminent."[2] Urban terrain presents a formidable communications problem because of the power constraints associated with man-portable radios, fading, and path loss.

The fact that man-portable radios are restricted to battery power limits the amount of data one can send. The transmitted data rate depends on the carrier frequency, signal bandwidth, radiated power, signal waveform, transmitting and receiving antenna gains, hard-

[1]One goal of DARPA's Small Unit Operations program is to develop a mobile wireless communication system for widely dispersed tactical units. This equipment will be capable of supporting a tactical internet based on dismounted soldier and mounted vehicle nodes without having to rely on a fixed ground infrastructure, essentially a "communication on the move" capability. The most promising type of system would be a mobile mesh network of communication nodes that are able to buffer, store, and route packets of information.

[2]Office of the Secretary of Defense, *1999 Joint Warfighting Science and Technology Plan (JWSTP)*, Chapter VIII, Military Operations in Urbanized Terrain, section D.

ware complexity, and the attainable signal-to-noise ratio (SNR).[3] At higher frequencies the larger channel bandwidths are generally wider, thus allowing more refined waveforms that improve the amount of information each signal can carry. The tradeoff is that while higher frequencies can support higher information rates, they often require more power to avoid getting blocked, larger antennas, and more expensive equipment.[4] The overall system can be optimized by making tradeoffs among various performance measures such as bit error rate (BER) and spectral and power efficiency. These tradeoffs dictate the choice of modulation, signal processing, and antenna techniques used to mitigate channel impairments and restrictions.

The characteristics of the propagation path between the transmitter and receiver—the number of obstructions, whether those obstructions are moving or not, the materials they are made of, etc.—impose fundamental limits on data rate. Urban terrain is one of the most difficult types of terrain in which to communicate because of fading and path loss.

Fading—which refers to a temporal variation in received signal strength—occurs because of multipath propagation. Multipath propagation results from the presence of reflecting objects and scatterers in the propagation path. Depending on the nature of the obstacles that caused the multipath, the received signal will experience fading.[5] Fading occurs when direct waves and reflected waves from

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[3]Some definitions: carrier frequency is the center frequency of the channel occupied by the signal. The bandwidth of a given signal is determined by the waveform of the signal. It must not exceed the width of the assigned channel. Waveform is a way to share a given band of frequencies among a population (modulation and error control coding). Modulation is the process of encoding information into the amplitude, phase, and/or frequency of a transmitted signal.

[4]This is why it is difficult to build man-portable radios capable of high-enough data transfer for video transmissions.

[5]There are two kinds of fading: flat fading and frequency-selective fading. In flat fading, the entire signal spectrum fluctuates uniformly in amplitude. In frequency-selective fading, different portions of the received signal spectrum will fade at various rates. To cope with frequency-selective fading, more signal processing is required. For more information, see Theodore S. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, 1995, Chapter 4, and David Goodman et al., *Evolution of Untethered Communications*, Washington, D.C.: National Academy Press, 1997, Chapter 2.

the same signal arrive at the receiver along different paths and at different phases and are therefore subjected to destructive interference (see Figure 2.1).[6]

Path loss is a function of the distance between transmitter and receiver. Path loss also occurs when radio signals are attenuated as they pass through or around walls, buildings, and objects in the channel.[7] Signal energy is absorbed or reflected as it encounters various objects. Path loss is a term used to quantify the difference (in dB) between transmitted power and received power and can be partly overcome with increased transmit power, special types of antennas, and other solutions.

In the urban environment, building construction materials, building age, wall locations, and ceiling heights determine path loss. Major obstacles include steel slabs, metallic pipes, and ventilation ducts. Concrete is worse than brick, and brick is worse than limestone. More windows help radio propagation, although the presence of metallic tinting in windows can hinder propagation.

Floor level also matters. In general, the signal strength received inside a building increases with height because there is less urban clutter at higher elevation. In the lower floors of a building, the urban clutter induces greater attenuation and reduces the level of signal penetration into the building. The exception is when several other tall buildings are adjacent. In this case, locating a radio on the middle floors rather than lower or upper floors is best when building penetration loss is the concern.[8]

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[6]The most common fading countermeasures are diversity, coding and interleaving, and adaptive modulation. Spread-spectrum techniques also mitigate fading effects. See Section 2.1.5.2 of Goodman et al., *Evolution of Untethered Communications*, op. cit.

[7]Attenuation and signal variation caused by objects in the channel that block the signal transmission is sometimes called shadow fading. According to Goodman et al., "The impairments inherent in any wireless channel include the rate at which received signal power decreases relative to transmitter-receiver distance (path loss), attenuation caused by objects blocking the signal transmission (shadow fading), and rapid variations in received signal power (flat fading)."

[8]Tall buildings that are adjacent can create shadowing effects that increase penetration loss at the highest floors. See Theodore S. Rappaport, *Wireless Communications: Principles and Practice*, Prentice Hall, 1995, p. 132.

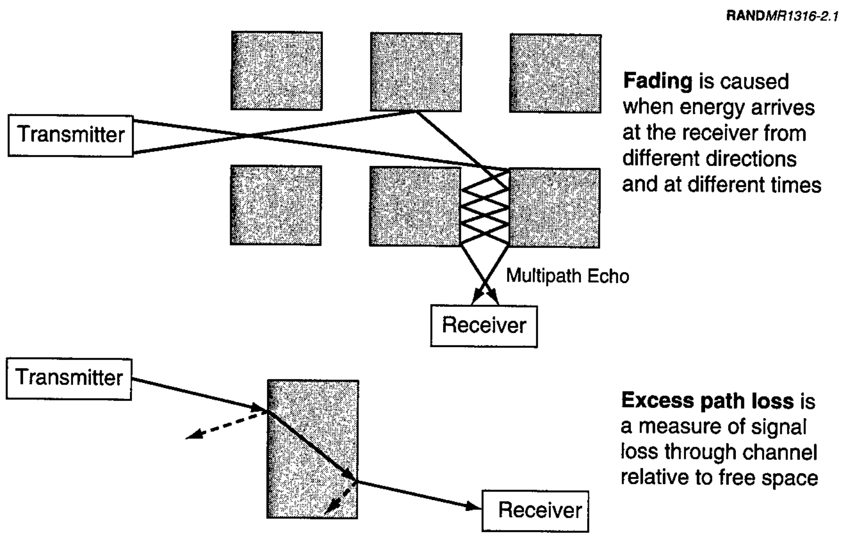

Figure 2.1—Fading and Excess Path Loss

Path loss should be measured for VHF and UHF frequencies and published in the appropriate training manuals so that soldiers and Marines can be made aware of the common types of materials that cause path loss for military radios. Several commercial studies are available that show average signal loss measurements of cellular radio waves passing through different numbers of floors or different building materials.[9] One example appears in Figure 2.2, which shows signal losses in decibels for radio paths obstructed by common building materials.[10]

Another problem for man-portable radios is the lack of adequate power sources. Radio operators must often carry their own power supplies in the form of batteries, and battery life is usually short.[11]

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[9]Ibid., pp. 123–132.

[10]Ibid., p. 125.

[11]Another problem is the lack of standardization among battery types. Currently there are literally hundreds of types, which increases the cost and burden of logistics. Greater standardization of battery types would probably lower the amount of overall battery weight a unit must carry.

Material Type	Loss (dB)	Frequency
All metal	26	815 MHz
Aluminum siding	20.4	815 MHz
Foil insulation	3.9	815 MHz
Concrete block wall	13	1300 MHz
Loss from one floor	20–30	1300 MHz
Loss from one floor and one wall	40–50	1300 MHz
Light textile inventory	3–5	1300 MHz
Chain-like fenced-in area 20 feet high containing tools, inventory, and people	5–12	1300 MHz
Metal blanket: 12 square feet	4–7	1300 MHz
Light machinery: < 10 square feet	1–4	1300 MHz
General machinery: 10–20 square feet	5–10	1300 MHz
Heavy machinery: > 20 square feet	10–12	1300 MHz
Ceiling duct	1–8	1300 MHz
Concrete floor	10	1300 MHz
0.6 square meter reinforced concrete pillar	12–14	1300 MHz
Sheetrock (3/8 inches): 2 sheets	5	57.6 GHz
Dry plywood (3/4 inches): 1 sheet	1	9.6 GHz
Wet plywood (2/4 inches): 1 sheet	19	9.6 GHz
Aluminum (1/8 inches): 1 sheet	47	9.6 GHz

Figure 2.2—Average Signal Loss Measurements Caused by Common Building Materials

Scarce power constrains the signal processing capabilities and transmission power of the mobile terminal, motivating efforts to keep man-portable radios as simple as possible.

WARFIGHTER DEMAND FOR COMMAND, CONTROL, AND COMMUNICATIONS

Because of the ongoing digitization efforts of the Army and the Marine Corps, warfighter C3 demands are increasing. As articulated in the Army's warfighting paradigm *Joint Vision 2010,* the goal of information superiority will require unprecedented amounts of information to be made available to soldiers. Key questions remain, particularly with regard to data type, quality, destination, and timeliness. Communication systems must be managed as a scarce physical resource. Many experts are working to find the right balance between information supply and demand for various command echelons. Too much information can lead to overload, and too little information would preclude optimum use of emerging technologies. For example, a battalion commander may find a real-time video teleconference with his company commanders a useful capability, but a fire team leader in charge of clearing the floor of a building may only need voice and positional data.

Determining the appropriate information demands of 21st-century soldiers is a complex problem that will continually evolve as the services conduct additional field experiments to test the impact of new technologies. Both scientists and users must work together to assess the value of new equipment, to make the necessary tradeoffs (dropping current equipment to make room for the new), and possibly change existing TTPs.

The warfighting and technical communities have produced several lists of warfighter requirements for C3 in urban operations, including Urban Warrior, the 1999 Joint Warfighting Science and Technology Plan, and the MOUT ACTD.[12] Since the MOUT ACTD C4I requirements were developed first, they are a useful place to start.

Table 2.1 describes these requirements and their current status. "Frustrated" means the requirement still exists but the MOUT ACTD no longer spends effort on it because (1) there was no mature, available product to put in a warfighter's hands now, or (2) the located products did not prove to be operationally viable during field testing. The MOUT ACTD representatives looked at both commercial and noncommercial technologies.

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[12]The MOUT ACTD is a joint program run by the Army Dismounted Battlespace Battle Lab (DBBL) and the Marine Corps Warfighting Lab (MCWL). It is the venue for integrating and demonstrating advanced technical and operational solutions to 32 specific user requirements for echelons at battalion or below operating in urban areas. Urban Warrior was a Marine Corps program that culminated in March 1999 with an AWE that took place at different California venues in Oakland, Monterey, and San Francisco. A series of tutorials called X-files contains many of the post-training analysis and feedback from Urban Warrior. See bibliography. The *1999 Joint Warfighting Science and Technology Plan* (JWSTP) has a chapter on MOUT which lists many functional capabilities that warfighters desire. See Chapter VIII, "Military Operations in Urbanized Terrain," found at *https://ca.dtic.mil/dstp/ 99_docs/jwstp/jwe.htm.*

Despite the fact that some DoD organizations appear to be less enthusiastic than the MOUT ACTD about leveraging commercial equipment, the MOUT ACTD findings give a good snapshot of where the technology is today.[13] For example, soldiers still need to detect a hostile through the walls of a room from a safe distance away. Current technology consists of a heavy hand-held device that must be placed right up against the wall, and the complexity of its audio feedback makes training difficult. Soldiers also need anti-sniper devices, but the MOUT ACTD investigators were frustrated in their efforts to find a viable technology. On a more positive note, hands-free voice communication worked well during the field tests, and soldiers were enthusiastic about this technology.

CURRENT DOCTRINE ON COMMUNICATING IN URBAN AREAS

Current field manuals offer limited advice on how to alleviate the problem of communicating in the city, which suggests that much work remains. In general, military manuals focus on site location, proper training, and other practical considerations such as cover and concealment and avoiding interference. They counsel that site location should be selected with electromagnetic characteristics in mind (avoid steel bridges, tunnels, underpasses, pole wire lines, etc.), should be quickly relocated if necessary to avoid deadspace,[14] and should use frequencies in the 50–75 MHz range.[15] Several variations in the physical position of the antenna should be tried to determine the best operating position to radiate the greatest amount of energy in the desired direction.

[13]CECOM, DARPA, and others are concerned about the security and frequency-allocation problems associated with commercial off-the-shelf technologies.

[14]A VHF or UHF signal ideally reaches a receiver by following a simple line-of-sight (LOS) path. When such a signal encounters an object in its path, and the object's dimensions are small in comparison with the signal's wavelength, radio energy will curve or bend around the object like ocean surf flows around rocks along the shore. If a large object is in the path, radio energy is blocked from the far side, creating a "dead spot" or blacked-out area.

[15]See Marine Corps Warfighting Publication 3-35.3, *Military Operations on Urbanized Terrain (MOUT)*, 1998, p. 4-19, and Field Manual (FM) 24-18, *Tactical Single-Channel Radio Communication Techniques*, 1987, Chapter 4.

Table 2.1

Some Operational Command, Control, and Communications Requirements, MOUT ACTD

Req. #	Description	Anticipated Residual Products	Status
R1	Identification of friendly, enemy, and noncombatants: The ability to identify and discriminate friendly/enemy and combatants/noncombatants at greater ranges and during all conditions.	No mature technologies found in timeframe to participate in MOUT ACTD	Frustrated requirement. Combat ID for Dismounted Soldiers (CIDDS) looks promising for the future.
R3	Hands-free non-line-of-sight communication.	Soldier ICOM (Army legacy) Kenwood Radio (USMC legacy) Shark Headset (USMC legacy)	Active. Currently trying different configurations, continuing testing of radios. Shark headset will be transitioned to LW.
R4	Produce/update maps: The ability to produce maps (complete with grid-lines) which are updated and accurate (based on some form of aerial imagery) and distribute down to at least squad level within 6–12 hours of notification. Ideally 1:25,000 scale or smaller, but as a minimum 1:50,000 scale. Maps should be updated, GPS-true maps with geographical information.	Arcview (Army)	Active. Army looking at Arcview, a battalion-level software asset that is essentially a database of digital maps. USMC would like to have near-real-time access to GPS grids and 1:5,000 maps, but this capability will not be available for at least 2–3 years minimum. NIMA/NRO do not have entire Earth's surface in a database yet.

Table 2.1—continued

Req. #	Description	Anticipated Residual Products	Status
R5	Intelligence collection/dissemination: A small unit (platoon/squad) intelligence collection and dissemination tool that conducts remote route/area/building reconnaissance. The platform should be single man portable and include at a minimum day/night audio/video. Ideally, the platform could accept a family of modular multisensor capabilities (e.g., through-wall sensors, countersniper sensors, etc.) and produce data that is compatible with higher-level communications architecture.	Shotgun (Army) Pointer UAV (Army)	Active. The Pointer is a hand-launched UAV carrying thermal and TV sensors currently used at battalion level.[a] Current UGV platforms were not mature enough (problems with mobility). In general, there is no single answer for unmanned systems and future warfighters will have to rely on a suite of specialized systems. Waiting to test "shotgun" system in 9/00.
R7	Through-wall sensor: A small, hand-held through-wall sensor to rapidly sense through walls and determine if the next room is empty or occupied by friendly/enemy or combatant/noncombatant.	No technology products successful in experimentation.	Frustrated requirement. A British Portaguard hand-held doppler radar-motion detector was tested but the feedback was audio, which exacerbated training requirements. Warfighters need a standoff sensor that does not require them to actually stand next to wall or building.
R33	Detect sniper: The ability to detect the location of sniper and small arms fire under all conditions from moving and stationary soldiers and vehicles.	No technology products successful in experimentation.	Frustrated requirement. Data sent back to R&D community. Testers found that current optical systems could not differentiate from the optical clutter of urban environment, acoustic systems could only detect *after* the first shot, and current technologies were not accurate enough on the move. Some of these anti-sniper systems might be acceptable for different missions such as fire base defense. More sensor fusion needed.

Table 2.1—continued

Req. #	Description	Anticipated Residual Products	Status
R36	Hand-held target designator: A lightweight, hand-held, common designator which is capable of designating or transmitting digital target data to off-site shooters, targets for USAF, artillery, naval munitions, Army aviation, and mortars.	No mature technologies found in timeframe to participate in MOUT ACTD. Added a thermal camera and tracking head to SOFLAM as a possible interim solution.	Tried the SOFLAM laser, but it shakes too much. A Light Weight Laser Designator Rangefinder may be available in 2005–2006.
R41	Position location in building: A position-locating device which provides position location data inside buildings.	No mature technologies found in timeframe to participate in MOUT ACTD.	Frustrated requirement. There is nothing beyond GPS. Dead reckoning systems were looked at (which fix position based on number of steps and direction from last fix), but stairs and other unique features caused problems.

[a]Some people suggest that UAVs be assigned to scout platoon or weapons platoon leaders. Experiments using the Pointer as a squad or platoon UAV showed that the maintenance and training requirements are very demanding for these low command echelons. Since infantrymen must already train to be proficient at many other infantry tasks, adding a complex ISR asset such as the Pointer would require that other training tasks be dropped.

SOURCES: Much of the information in this table was gathered during a teleconference arranged by the MOUT ACTD Technology Program Office on April 18, 2000, between the author and the following experts: Carol Fitzgerald, Robert Zirkle, Adam Fields, Sam Spears, Andrew Mawn, and Cynthia Blackwell. Other evaluation information was gathered from representatives at the TRADOC Analysis Center (TRAC) and Ken Christy and Robb Hight at the MCWL. The author chose not to include two MOUT ACTD C4I requirements: R2 (powered optics) and R6 (night vision).

NOTE: According to MOUT ACTD, the use of a trade name or the name of a manufacturer or a contractor in this table does not constitute an official endorsement or approval of such commercial hardware, software, or service. This table may not be cited for the purpose of advertisement.

The primary urban operation manuals—Field Manual (FM) 90-10, *Military Operations on Urbanized Terrain* (1979) and Field Manual (FM) 90-10-1, *An Infantryman's Guide to Combat in Built-up Areas* (1993)—stress the importance of retransmitting, either with organic radio sets or by using aerial platforms, if they are available. They suggest that radios and relay stations should be placed on top of tall structures to increase range. Alternative means of communication are also mentioned, including the use of wire, messengers, visual and sound signals, pyrotechnics, and the existing commercial infrastructure.

The Marine Corps Warfighting Publication 3-35.3, *Military Operations on Urbanized Terrain (MOUT)* (1998), offers a little more detail. Visual and sound signals are mentioned, but these signals are usually hard to discern in urban areas because of high background noise levels, the screening effects of walls, etc. Existing telephone lines are another option (but security is a problem), and human messengers are noted as reliable.[16] Wire is recommended when establishing the defense, for fire support communications, and for squads clearing subterranean areas.[17] Table 2.2 provides a summary of these alternatives to wireless communications.[18]

Many of these tips are common sense or have been learned the hard way from past mistakes. For example, "using commercial infrastructure" has been overlooked in the past. During Operation Market Garden in 1944, not one member of the trapped British 1st Airborne Division in Arnhem thought to pick up a commercial telephone to contact allied reinforcements when many of their radios turned out to be useless.[19]

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[16]Marine Corps Warfighting Publication 3-35.3, *Military Operations on Urbanized Terrain (MOUT)*, 1998, pp. 3-27 and 4-7.

[17]Ibid., pp. 4-6 and E-2.

[18]Other military manuals that the author looked at include FM 11-1, (MCRP 6-2.2.2), *TALK II—SINCGARS Multi-service Communications Procedures for the Single-channel Ground and Airborne Radio System,* May 1996; FM 34-41, (FMFM 3-350), *Multi-service Procedures for Spectrum Management in a Joint Environment,* 1994; and FM 24-18, *Tactical Single-Channel Radio Communication Techniques,* 1987.

[19]On the other hand, in Grenada in 1983, one American soldier successfully placed a long distance, commercial telephone call to Fort Bragg, North Carolina, to obtain C-130 gunship support for his unit, which was under fire at the time.

Table 2.2

Alternatives to Wireless Communications

Alternative to Wireless Communication	Examples	Manuals Referencing It
Use wire communications	Field telephone wire landlines can be laid underground or through buildings for primary, alternate, and supplementary positions	MCWP 3-35.3 FM 90-10 FM 90-10-1
Use commercial infrastructure	Use the telephone distribution box in the building or the television antenna on the roof	MCWP 3-35.3 FM 90-10 FM 90-10-1 FM 7-98[a] *ACE MOUT Manual*
Position or use communications with electromagnetic characteristics in mind	• Avoid metallic objects • Near buildings with iron beams or metal roofs, position radios 2–5 times the height of intervening building away from that building[b] • Avoid sunrise and sunset[c]	MCWP 3-35.3 MCWP 6-22
Use visual signals	Mirrors, lights, wing or rotor dips, air panels, flags, chemlights, spray paint, engineer tape, chalk, flares, colored smoke, tracers, flash cards, infrared strobes, laser pointers, luminescent paint, hand and arm signals	MCWP 3-35.3 FM 90-10 FM 90-10-1 *ACE MOUT Manual*
Use acoustic signals	Bells, whistles, voice, pyrotechnics, metal-on-metal, rifle shots	MCWP 3-35.3 FM 90-10-1

Table 2.2—continued

Alternative to Wireless Communication	Examples	Manuals Referencing It
Use human runners	The age-old solution	MCWP 3-35.3 FM 90-10 FM 90-10-1
Position radio relays and antennas on top of buildings	A marine standing on top of a building with a SINCGARS radio	FM 90-10 FM 90-10-1 *ACE MOUT Manual*[d]
Retransmission with aerial relays	Retransmission stations in aerial platforms can provide the most effective means if they are available	FM 90-10 FM 24-18
Bounce signals off stone or brick walls	Directional antennas can use stone or brick walls as passive retransmitters to bound signals down a street[e]	*ACE MOUT Manual*

[a]See *Operations in a Low-Intensity Environment,* Field Manual (FM) 7-98, Chapter 6, "Command, Control, Communication, and Intelligence."

[b]*Aviation Combat Element (ACE) MOUT Manual,* MAWTS-1, Edition V, USMC, 1997, recognizes that line-of-sight radio transmissions are likely to be degraded by intervening high-rise buildings at altitudes below 500 feet.

[c]See *Communications and Information Systems,* MCWP 6-22, 1998, which notes that communication planners must take into account the electromagnetic environment in the area of operations, including not only terrain but the time of day. The sun's radiation causes disturbances in the ionosphere; and sunrise and sunset can be the most difficult times for high-frequency communications (p. 5-4).

[d]The *ACE MOUT Manual,* MAWTS-1, notes that PRC-77s worked well in Hue when placed on top of buildings (p. 1-16).

[e]The *ACE MOUT Manual,* MAWTS-1, also instructs the soldier to position retransmitters at crossroads to communicate with units on perpendicular streets (p. 4-73).

Recent lessons from urban operations experiments verify that soldiers need flexible approaches to maintaining communications. The Marines learned how to alleviate C3 problems during Urban Warrior, employing solutions such as using wire on defense, placing radiomen on top of buildings, and using maneuver (if they could not communicate from where they were relocated). They noted that visual hand and arm signals did not work well. Visual signals—particularly pyrotechnics—were found to be problematic within buildings and enclosed spaces.

Chapter Three

NEAR-TERM SOLUTIONS (0–3 YEARS)

History offers many examples of how limitations to command, control, and communications can be overcome. In some cases, an alternative technology replaced the old communications means and doctrine remained unchanged. In other cases, only the doctrine changed. In most cases, however, both tactics, techniques, and procedures (TTPs) and technology were changed.

A case where both TTPs and technology were changed can be drawn from infantry/artillery tactics in World War I. At the beginning of the war along the western front, commanders lost contact with their assault troops when they entered "no man's land" because field telephone wires were vulnerable to artillery fire. As a result, when subordinate units went "over the top" they entered a black hole from which no further communication was possible with the overall commander (except by runner). No communication meant that all coordination between the rolling artillery barrages and the advancing infantry had to be preplanned. All too often the infantry got bogged down during their advance and ended up watching in helpless horror as their protective artillery barrage "walked off." TTPs were adjusted to use *Very* pistols as a signal to artillery support after telephone communication was lost.

A second example of successful employment of a simple technological innovation occurred during air/ground operations in the Six-Day War. In the 1967 battle for Jerusalem, the Israeli Defense Force (IDF) placed Israeli flags on top of cleared buildings so that aircraft providing close air support (CAS) could monitor the Israeli forward line of troops (FLOT). They also used a spotlight during the night to mark specific buildings as close air support targets.

POSSIBLE DOCTRINAL CHANGES TO IMPROVE C3

There are two reasons why a change to doctrine might be useful. First, if the C3 requirements of a mission cannot be met by available technology, then warfighter demand for C3 may need to be reduced. Second, the utility of an improved or new C3 technology may be fully exploited only by appropriate changes in doctrine or organization.[1]

It is beyond the scope of this monograph to offer detailed changes to TTPs that are based on the accumulated experience and expertise of thousands of professional soldiers.[2] Our doctrine already recognizes the importance of command, control, and communications in planning and conducting military missions. Commanders are always taught to analyze each situation to determine how the terrain, weather, and enemy might affect their ability to communicate. This monograph merely suggests that our reliance on situational awareness for emerging operational concepts requires us to focus even more on the communications problem. The recommendations below recognize the increasing importance of data to the warfighter and suggest four areas for possible change: "leverage the urban terrain," "plan the scheme of maneuver," "recognize situational awareness zones," and "change coordination mechanisms."

[1]It is important to ask whether the adoption of any new C3 technology necessitates changes in doctrine or organization. Often throughout military history, new weapons were best exploited by appropriate changes in doctrine and organization; the same may be true for some C3 technologies. In the past, technological advances in C3 have allowed armies to exercise greater dispersion, coordination, and maneuver. For example, before 1800 AD, the technological limitations of command prevented a single leader from directly controlling any formation larger than three thousand men in the field because that is the maximum number of men who can see or hear the same signal (see Martin van Creveld, *Command in War*, op. cit., pp. 24–27). It was difficult for field commanders to split their army into many parts because the primitive means of communication available—whether it was couriers, visual signals such as standards, or acoustic signals such as trumpets—were either too slow or of limited range. With the advent of the telegraph (with the railroad) in the 19th century and the radio (with the combustion engine) in the 20th century, C3 technologies played a major role in the changing doctrine and organization of the dominant military system.

[2]Of course, changes to doctrine must be considered carefully. If a new training task is given to a soldier, an old task may have to be dropped to make room in the soldier's training schedule. A greater focus on communications means a lesser focus on something else. Further study and experimentation would help us understand how to make that tradeoff.

Leverage the Urban Terrain

Any soldier knows that leveraging terrain is a key to success on the battlefield. Terrain features such as hills, valleys, roads, rivers, and forests all affect movement, offensive and defensive tactics, lethality of fire, camouflage and concealment, and command, control, and communications. As the U.S. Army continues to add computers and radios to its vehicles and soldiers, commanders preparing for the urban fight should spend more time viewing urban terrain from a communications perspective. Commanders should remind their soldiers to seek the high ground; to regularly use tall buildings as base stations or relays; and to camouflage military wire communication lines amongst the civilian communications infrastructure (situated around existing telephone/electrical poles, for example). In deliberate attack missions where the objective is a known, fixed target like a large building, do commanders and staff officers access the architectural drawings of the building to determine the propagation characteristics of key floors, areas, or walls?

"Obstacle amplification" is one technique to amplify signals using building structures as reradiators. In Grozny, the Russians learned to use directional antennas to bounce radio waves off stone or brick walls to propagate their signals down a street. The building walls acted as reradiators to increase the strength of wireless transmission. Recognizing that certain buildings could be used to amplify their signals, the Russians located transmitters and receivers along routes where radio waves could reflect off buildings.[3]

When the Marine Corps tested the vulnerability of intra-squad radios to enemy detection, they noted that "signal tunneling" occurs when an urban canyon lies between the transmitter and the radio detector. The buildings along the sides of the canyon effectively concentrated

[3]Evidently the Russians used buildings as reradiators in Berlin and Koenigsberg during the Great Patriotic War (World War II). They were also used as passive relays. For example, a radio signal could be sent along a street to bounce off a stone building at an intersection in order to communicate with a receiver located on a perpendicular street. See Colonel Vitaliy Kudashov and Major Yuriy Malashenko, "Communications in a City," *Armeyskiy Sbornik*, Translated by FBIS, January 1, 1996.

the signal, increasing the chance of enemy detection (compared to open-terrain tests).[4]

Plan the Scheme of Maneuver

In general, one of the primary concerns of a commander is to maintain command and control when developing his scheme of maneuver.[5] There are several ways to prioritize communications during unit maneuver. For example:

- Avenues of attack, strongpoints, rally points, phase lines, and other critical locations identified in the operations order can be chosen with greater consideration for electromagnetic propagation characteristics.
- As long as the primary considerations of cover, concealment, and mission are accounted for, radios (and by extension, the unit that carries them) should be positioned away from steel-reinforced buildings and other metallic infrastructure that might interfere with transmission.
- Fire and movement TTPs can be changed for crossing electromagnetic deadspace and then changed back to normal once the special areas are traversed. For example, if you know the deadspace area will prevent individual computers from receiving data, soldiers can reduce their separation distance and coordinate with each other using hand signals and pyrotechnics.
- Maintain LOS between adjacent units when maneuvering across known deadspace areas so that no single unit is ever physically isolated and cut off from communications. Perhaps the maneuver should be more linear across electromagnetic deadspace.

[4]Department of the Navy, *Commercial Off-The-Shelf Radio Technology: An Evaluation of Radio Technologies to Support the Marine Corps of the New Millennium*, Marine Corps Warfighting Lab, p. 45.

[5]The scheme of maneuver describes how arrayed forces will accomplish the commander's intent. It is the central expression of the commander's concept for operations and governs the design of supporting plans or annexes. Planners develop a scheme of maneuver by refining the initial array of forces and using graphic control measures to coordinate the operation and show the relationship of friendly forces to one another, the enemy, and the terrain. See *Staff Organization and Operations*, Field Manual (FM) 101-5, May 1997.

- Avoid the deadspace altogether if the mission allows it. Isolate and bypass, leaving it for later mop-up.

As the U.S. military moves to a more digitized force that relies on constant situational awareness as a force multiplier, commanders will probably have to deploy and maneuver their soldiers with a more careful eye to the propagation characteristics of the environment. Given enough time and resources, intelligence preparation of the battlefield (IPB) should include an analysis of an area's propagation characteristics for various maneuver options. In some scenarios it may be feasible to use a radio prediction model during the planning of the scheme of maneuver.

For example, consider the data from a recent Marine Corps analysis of Rosslyn, Virginia.[6] A three-dimensional radio prediction model from the Schafer Corporation simulated thousands of signals from a transmitter and bounced them off building faces until they either intercepted the receiver or exited the model. This model provided theoretical performance data on path loss and multipath calculations.[7] For example, Figure 3.1 shows the urban canyons in Rosslyn and the location of the transmitter and receiver for two particular simulations. Whether the propagation path between the transmitter and receiver was in line with major streets or perpendicular to them was a major factor. The propagation path between transmitter A and the receiver is "in line." The propagation path between transmitter B and the receiver is more perpendicular. The Schafer model correctly predicted that path loss (in decibels) was lower for transmitter location A than for transmitter location B.

This is just one example of how commercial radio prediction models can help commanders anticipate where command and control problems may arise. A commander's scheme of maneuver could take into account how the layout of streets affects C3. For example, if a battalion commander is planning deliberate attack on several blocks of city core terrain, he may want to keep his headquarters stationary for the duration of the mission. Alternatively, he could

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[6]Rosslyn was used to conduct the field tests because it offered typical urban canyons with buildings ten or more stories tall.

[7]Later field measurements of path loss matched the Schafer model closely.

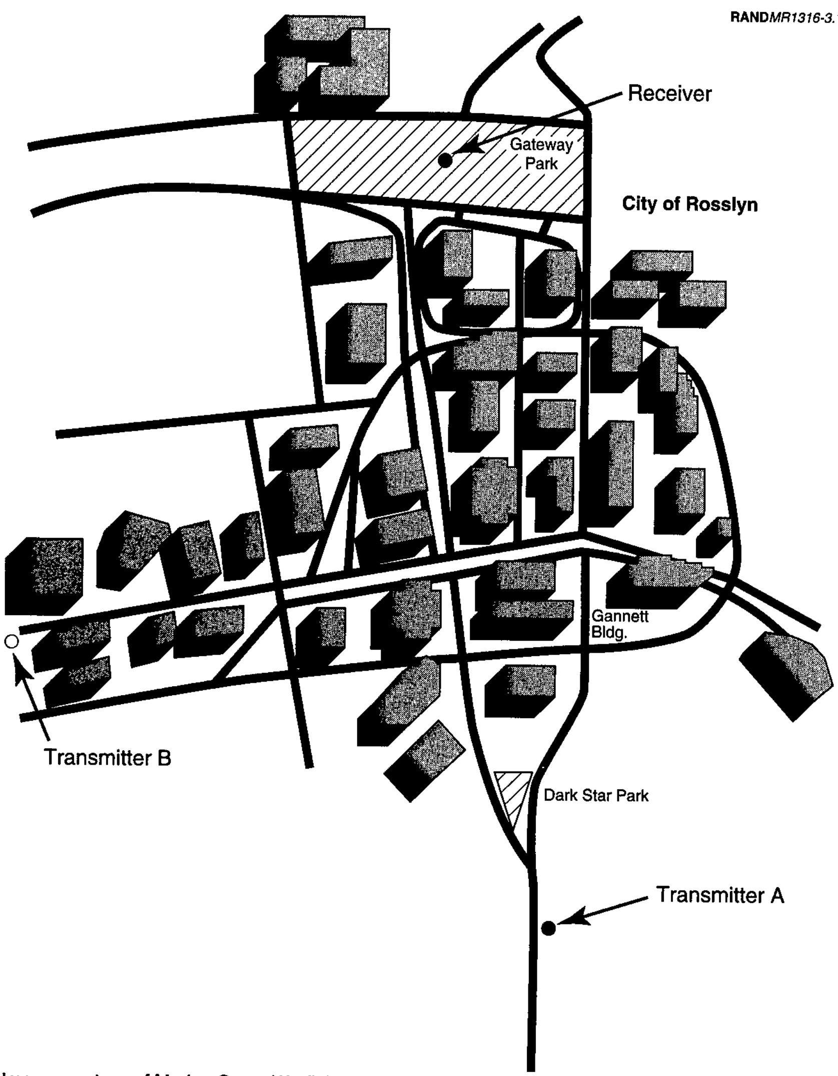

Image courtesy of Marine Corps Warfighting Laboratory.

Figure 3.1—Transmitter and Receiver Locations in Rosslyn, Virginia

preplan a series of new headquarters positions that progress with the assault and allow excellent radio coverage. IPB analysis should determine how building-to-building and street-to-street propagation looks before his units begin to maneuver. Whether the main thoroughfares are perpendicular or in line with his headquarters communications nodes is critical to determining which of his subordinate units continue to receive SA updates.

Recognize Zones of Situational Awareness

Some areas or zones of urban terrain will always prove to be obstacles to wireless transmission, and it may make sense for a commander to train his troops to use a second set of tactics, techniques, and procedures when fighting within these zones. In geographic zones where SA is severely limited—such as sewers, subway systems, underground WMD facilities, and other subterranean structures—alternative TTPs may be necessary that rely on more basic means such as wire or voice.

For example, a strong case can be made that C3 TTPs are already different for areas within buildings as opposed to areas between buildings, wireless transmissions are not that critical for close-quarters fighting within buildings, and effective room clearing can be done without the use of radios.[8] Voice and visual signals are sufficient to communicate inside enclosed spaces because of training, known objectives, and SOPs.[9] Urban Warrior showed that for close-

[8]Even though room and building clearing is done effectively at present, trainers would still like to get a radio that would reduce the need for shouted commands. English is one of the most widely understood languages in the world.

[9]According to observer/controllers at the Shugart-Gordon MOUT training facility, a problem area for current training continues to be movement between buildings, not clearing buildings. When the observers/controllers were asked "Given the fact that urban operations requires a detailed plan for fire and maneuver, good graphic control measures, and a plan to deal with possible degraded communications ability, what unique command and control techniques have you seen implemented by units that have been able to efficiently maintain control of their subordinate elements during urban engagements?" the group hesitated a moment and then in unison said "Nothing." They agreed that the close quarters combat techniques in Appendix K of FM 90-10-1 were a solid doctrinal base for clearing buildings. They thought the problem area was in the streets and between buildings. See *CALL Newsletter No. 99-16: Urban Combat Operations*, Chapter 3, "Command and Control." Also based on

quarters fighting inside buildings, human messengers were more effective than radios at identifying focal points for attack because of enemy jamming and too much talking by friendly units.[10] Between buildings is the area where wireless communications is most needed. Urban Warrior confirmed that the streets are the enemy's killing zones, not the interior of buildings.[11] Most MOUT casualties occur as units move outside of buildings, and poor SA is the primary cause.[12]

In other cases, lower situational awareness may not be dictated by the terrain but rather by the mission of the unit. For example, experience with Force XXI has shown that special units that roam a lot, operate in more dispersed formations, or move faster than normal require additional C3 resources, otherwise they suffer lower SA. Aviation units and other mobile scout units, called "fast movers," update the tactical internet at too slow a rate to keep proper track of their position and tend to outrun the coverage of their communication networks, which causes problems for standard internet protocol.[13] These problems may be solved, but similar problems with ground units in future urban operations will surely arise.

Whether the command and control problem is caused by a difficult mission or difficult geographic zone, the commander may wish to prioritize his scarce communications resources. By allocating different levels of communication to different units or zones, the commander enables different levels of SA. For example, he might designate critical or high-value communication assets—such as airborne communications relay platforms—for his maneuver elements because communication between two units is more difficult when transmitter and receiver are moving. Units that are in a fixed de-

comments by SSGT Robb Hight, MCWL MOUT ACTD Project Office, telephone interview, February 4, 2000.

[10]See *Urban Attacks Tactics, Techniques and Procedures (TTPs)*, X-File 3-35.1, pp. 14 and 29.

[11]See *Urban Patrolling Tactics, Techniques and Procedures (TTPs): Urban Warrior MOUT*, X-File 3-35.6, MCWL, p. 12.

[12]See *Fighting Light/Heavy in a Restricted Terrain*, Newsletter No. 98-10, Chapter 4, "MOUT Operations," found at *http://call.army.mil/call/newsltrs/98-10/table.htm* on March 6, 2000.

[13]See Rupert Pengelley, "Battling with Tactical Internets," *Jane's International Defense Review*, February 2000.

fense—such as a strongpoint—could take advantage of wired communications assets and optimal preplanned transmission pathways. In other cases, the commander might choose which units get bandwidth based on what is important for the mission at hand (whether it is intelligence, command, medical, or logistical in nature).

Time constraints on unit and individual training schedules must be accounted for. As commanders weigh the costs and benefits of getting rid of an old TTP to make room for a new one in the training schedule, they should remember that soldiers need to retain a baseline set of "traditional" TTPs that work without wireless communication. The fog of war will always exist, and wireless communications will not always be available. Chemlights, star clusters, hand and arm signals, and other traditional techniques will always be needed.

Change Coordination Mechanisms

Organizational theory can offer insights into how to reduce the need for communication within an organization.[14] Using other coordination mechanisms besides direct supervision, a commander can reduce the need for explicit communication both vertically (up and down the chain of command) and horizontally (between units at the same echelon) within his unit.

There are four basic mechanisms for achieving coordination in organizations: direct supervision, mutual adjustment, standardization, and explicit planning (see Table 3.1). The tradeoff between these four choices is in terms of cost and flexibility. The more that planning and standardization are used, the less the need for explicit communication (lower cost) but the more inflexible the unit. For example, standing operating procedures (SOPs) and planning can reduce the need for communication between units. Platoon comman-

[14]Organizational design determines the structure of a unit, the division of labor, and what must be coordinated with what. In effect, organizations are created to account for the individual cognitive limits of a single leader through specialization and the division of labor. John Crecine and Michael Salomone, "Organization Theory and C3," in Stuart Johnson and Alexander Levis (eds.), *Science of Command and Control: Part II, Coping with Complexity*, Fairfax, VA: AFCEA International Press, 1990, p. 48.

Table 3.1

Four Types of Coordination Mechanisms

Coordination Mechanism	Description	Cost
Direct supervision	Supervisor controls behavior of subunit members by allocating resources to subunits and by direct guidance	Heavy information processing burden on supervisors leads to bottlenecks and delays
Mutual adjustment	Two or more actors share resources	Requires very high rates of information transmission because every actor must communicate with every other actor
Standardization	SOPs govern behavior of subunits under specified conditions. No direct communication is necessary if subunits can anticipate which SOPs other subunits will implement	Requires significant lead time; excessively rigid behavior
Explicit planning	Direct supervision in advance	Requires significant lead time; excessively rigid behavior

ders can use tactical control measures to signal higher, adjacent, and subordinate units.[15]

[15]The unit commander implements tactical control measures to help control his unit, ensure unity of effort, and prevent friendly fire. Tactical control measures like phase lines, boundary markers, and zone identification help with planning and reduce the need for overt C3. For example, phase lines are placed along identifiable terrain features (streets, alleys) to control the rate of advance of assaulting units. Boundaries prevent a unit from straying into another unit's fire. Checkpoints placed at prominent intersections can be used to report position and to mark progress. Streets can be renamed for security reasons or if maps are not available. Buildings can be numbered or lettered to facilitate identification, control fires, and simplify reporting procedures. See the student handout on MOUT, Basic Officer Course, The Basic School, Marine Corps Combat Development Command.

The degree of centralization versus decentralization affects communication needs.[16] In general, hierarchical control systems require less horizontal communications between units than decentralized systems because a hierarchical organization only requires each actor to communicate with one superior and a small number of subordinates. Networked, decentralized organizations require more horizontal information flows (unless units are autonomous) but fewer vertical information flows. The downside for centralized organizations is that they fail to fully exploit local information and expertise.

The motto of U.S. joint doctrine is "centralized planning with decentralized execution."[17] Recently, support for a more decentralized command approach has appeared.[18] Since urban operations are typically characterized by small infantry teams using raids and ambushes to advance and maneuver along separated axes, small unit commanders need decisionmaking freedom to deal with the local tactical situation on the spot. One way for a commander to do this is to issue the *commander's intent*. The commander's intent describes the desired end state of the mission rather than listing detailed instructions on how subordinates are to accomplish their assigned tasks. This allows subordinates to exercise initiative and adjust to changing circumstances when they carry out their orders.[19]

Some authors suggest that the information revolution is centralizing command rather than decentralizing it despite what the formal doctrine states. Reports and narratives from the field indicate that Army operations have become steadily more centralized and that the

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[16]Most control systems are centralized in some respects and decentralized in others.

[17]See Chairman of the Joint Chiefs of Staff, *Doctrine for Joint Operations*, Joint Pub 3-0, 1995.

[18]Marine Corps doctrine calls for decentralized command and the use of mission orders in urban environments. See *Combat Squad Leader Decision Making: Urban Warrior MOUT*, X-File 3-35.2, MCWL, pp. 19–24.

[19]Most of these ideas are derived from the "maneuver warfare" school of thought and the German concept of *Auftragstaktik*. Historically speaking, decentralized armies that have allowed tactical commanders considerable latitude have often been very successful. Roman centurions and military tribunes, Napoleon's marshals, and Mongol *toumen* commanders all demonstrated how subordinate leader initiative can minimize the complexity of hierarchical top-down control and achieve dramatic success on the battlefield. See van Creveld, *Command in War*, op. cit.

commander's intent statement now gives detailed and lengthy guidance similar to a formalized checklist.[20]

COMMUNICATION TECHNOLOGIES

The obvious answer to improving urban communications is to improve or add wireless technologies. Several promising communication technologies are available (or will be in a few years). Military radios were first used by German panzer divisions in World War II, ushering in a new era of tactical communication that continues to the present day.

Military Radios

Currently, dismounted wireless communications only extend down to the platoon level. Squad leaders still rely on their voice and visual signals to give orders to their troops.

Most tactical military radios that are small and light enough to be carried by a soldier or marine are in the VHF and UHF frequency bands. VHF and UHF radios use relatively short wire antennas called whips. VHF and UHF radios have low power, weight, and costs compared to radios that operate at super-high frequencies (SHF) because there is greater path loss between whip antennas at higher frequencies. Compensating for this by using directional antennas increases weight and bulk. As a result, SHF radios require more input power to operate properly. High-data-rate LOS radios in the SHF band (sometimes referred to as microwave radio relay systems) are far too large for a soldier to carry and usually require small trucks to carry terminals and antennas.[21]

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[20]See Colonel Robert B. Killebrew, "Reinventing the Army for the 21st Century," *Army*, June 2000, p. 18.

[21]SHF man-pack systems exist, but the limited efficiency and capacity of the supporting space segment restricts the number of these systems within a given footprint. See Office of the Secretary of Defense, *C4ISR Handbook for Integrated Planning*, Office of the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence, 1998, pp. 2-9 and 2-18.

Many military radios have several possible configurations, including hand-held, man-portable, vehicle-mounted, and sheltered modes. Table 3.2 lists most of the U.S. military radios that are man-portable.[22]

VHF signals (30–300 MHz) usually require line of sight (LOS) between terrestrial transmitters and receivers and, in practice, are useful up to about 40 miles for a single hop. If the terrain is hilly or there are obstacles, the range will be reduced considerably. VHF radio systems are subject to disruption or fading as a result of mutual interference from other nearby radios, path obstructions, or deliberate jamming. Heavy rains and vegetation can also reduce signal strength. UHF signals (300–3000 MHz) are principally LOS.

VHF and UHF systems are essentially LOS, and the usable range will be determined by the intervening terrain. In general, LOS UHF terrestrial systems operate at somewhat reduced ranges compared to VHF systems.

SINCGARS. The single-channel ground and airborne radio system (SINCGARS) is the baseline for evaluating all other dismounted radios. First fielded in 1988 with a man-portable weight of 19.4 pounds (including battery), this VHF radio is the primary means of command and control for infantry, armor, and artillery units today. Over 200,000 man-portable, vehicular, and airborne versions are required by the Army alone. Jamming is countered by hopping 100 times per second through 2,320 available frequencies. Over the past 11 years SINCGARS has evolved from a voice-only radio, and it now includes secure voice, data communication, and networking capabilities. The upcoming advanced system improvement program (ASIP) model is half the weight and size of the current SIP model fielded by the Army, and its battery life is double that of the first-

[22]There are some high-frequency radios that are light enough to be man-portable, but most are mounted in vehicles, ships, and aircraft. High-frequency radios are mainly used for long-haul communications but are also employed for tactical military applications as a short-range mobile supplement to LOS radios for communication between stations separated by an obstacle (such as a mountain range). The primary limiting factors for HF radio use are propagation anomalies, frequency allocation, and bandwidth availability.

Table 3.2

Selection of Tactical Military Radios for Dismounted Use

Frequency Band	Model	Operating Frequency Range (MHz)	Description
VHF	AN/PRC-68[a]	30–88	Hand-held
	AN/PRC-126	30–88	Hand-held, 1.17 kg
	AN/PRC-132	1.6–50	SEAL, Special Forces Radio[b]
	AN/PRC-139	30–88	Hand-held special forces radio, very expensive
	AN/PRC-148[a]	30–88	Used by Special Forces (also known as the MBITR)
	SINCGARS (or AN/PRC-119E), SINCGARS (SIP), SINCGARS (ASIP)[a]	30–88	Army, Marine Corps, Air Force; replaces AN/VRC-12 and PRC-77 families
UHF	AN/PRC-113	116–150 225–400	Marine forward air control ground-to-air communications
	AN/VRC-83	116–150 225–400	Marine forward air control ground-to-air communications
	AN/PRC-117F[a]	30–512	Interoperable with SINCGARS
	AN/PRC-148	30–512	Special Forces Radio
	AN/GRC-171	225–400	Marine forward air control ground-to-air communications
	AN/ARC-210	225–400	Marine aviation radio compatible with SINCGARS; air-to-ground, ground-to-air
	AN/PSC-5	225–400	Provides tactical SATCOM, can link to satellite to reach a SINCGARS network that includes another PSC-5

[a]Tested as an ISR candidate by the Marine Corps; see the next subsection.

[b]The Joint Advanced Special Operations Radio System (JASORS) will replace the AN/PRC-132.

generation SINCGARS.[23] ASIP is compatible with SIP and the first-generation SINCGARS. In ASIP and SIP, GPS information is embedded in the waveform so that the radio's position is automatically transmitted as part of its digital data transmission.[24]

Commercial-Off-the-Shelf (COTS) Radios

The Marine Corps and the Army are currently experimenting with various commercial radios and mobile phones to see if these technologies are useful for military urban operations.

Marine Corps Intra-Squad Radio (ISR). The Marines need a radio that squad leaders can use to control their men in combat when voice or visual signals are impossible or impractical. They require an intra-squad radio (ISR) that is small, reliable, short range, lightweight, and easy to use, sending voice only. Marines feel that security is not a major concern with commercial radios because of the type and perishability of the information passed at the lowest tactical levels.[25]

The Marine Corps has evaluated 14 commercial and conventional military radios in its efforts to select an ISR. One of the most effective ISRs tested was the Kenwood Freetalk radio combined with a headset and microphone. This "surrogate for capability" had a tremendous

[23] 69,000 ASIP units were ordered from ITT Aerospace/Communications Division (A/CD), the first going to the 82nd Airborne Division and various special operation forces in the spring of 1999. The 15 enhanced brigades of the National Guard also planned to procure the SINCGARS ASIP. See Mark H. Kagan, "Redesigned Communication Equipment Strengthens First-to-Fight Operations," *Signal*, March 1999.

[24] According to ITT, ASIP's digital signal processing (DSP)-based architecture permits field reprogramming through external connectors for future upgrades, including electronic counter-countermeasures, communications security, and improved waveforms.

[25] In fact, the Marine Corps reports that the ISR's vulnerability to direction finding and intercept was low in the San Francisco Embarcadero experiment. See *Commercial Off-The-Shelf Radio Technology: An Evaluation of Radio Technologies to Support the Marine Corps of the New Millennium*, Marine Corps Warfighting Lab, p. 7. Security characteristics remain a concern for CECOM/DARPA, but some people question how much vital information is at risk between riflemen working to clear buildings, talking over a radio with a range of three miles. Comments by SSGT Robb Hight, telephone interview, February 4, 2000, MCWL MOUT ACTD Project Office.

impact at the company level and below, greatly increasing situational awareness.[26] The Marine Corps issued one ISR to every fire team leader, two to every squad leader, and one to the platoon leader and company commander.[27] Project Metropolis experiments have shown that adding ISRs allows infantrymen to avoid "stacking" and bunching before entering buildings, allows more dispersion in general, and reduces fratricide.[28] Coordination both within and among squads increased. For example, in previous training exercises where infantrymen did not have ISRs, several squads working next to each other tended to maneuver in a more isolated fashion, setting boundaries for themselves and conducting a series of frontal assaults within their boundaries. If squads are equipped with ISRs, they tend to coordinate more, where some squads lay down a base of fire while adjacent squads maneuver, etc. Tank/infantry coordination is also now possible at the fire team level, since tanks and armored vehicles use ISRs.[29]

Some SOPs changed while others remained the same. One new SOP limits transmit authority to key leaders only because initial tests showed that too little information was getting out.[30] Calls for fire

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[26]After the field experiments were completed, marines were polled. *One hundred percent* of them agreed that the radios allowed the user to perform his mission more effectively.

[27]At the time of this writing (summer 2000), Project Metropolis has only experimented with reinforced platoons or smaller units.

[28]Based on comments by Randy Gangle during telephone interview, August 15, 2000.

[29]At first the ISRs did not work well inside a "buttoned up" tank because of its metallic superstructure. To solve the problem, the Marine Corps developed an antenna that is mounted on the vehicle. Using ISRs in this way would help solve the longstanding communications problem between tankers and infantrymen. To this day, armor/infantry exercises at the Joint Readiness Training Center MOUT facility are still plagued by sporadic communications. The alternative is to mount on the outside of the tank a telephone handset that is connected to the tank crew's intercom. The Center for Army Lessons Learned (CALL) recently recommended an external intercom control unit for the M1A1 tank. See *Fighting Light/Heavy in a Restricted Terrain*, Newsletter No. 98-10, Appendix C, "Ground-to-tank Communications," found at *http://call.army.mil/call/newsltrs/98-10/table.htm* on March 6, 2000.

[30]Caused by emotional outbursts by soldiers—78 profanities alone in one 30-minute time span. The Marine Corps is also trying new tactics such as the "tactical bubble." This was developed for situations where units are not contiguous and must maneuver independently. The unit, whether it is a platoon, company, or battalion, adopts a 360-degree offensive/defensive posture and remains prepared for a meeting engagement as it maneuvers across city blocks.

Table 3.3

Assessment of 14 COTS Radios for Urban Scenario

Scenario	Description	Number of Successes
Street to street	Distances tested varied between a few hundred yards to 1/2 mile	11
Exterior to interior	Exterior street to building interior	9
Subterranean	Street to subterranean*	0
Building penetration	Within-building communication through one to ten floors of the Hyatt Arlington	10

*Communication was possible between the underground upper platform to elevated structures and between the underground upper platform to subterranean levels.

SOURCE: *Commercial Off-The-Shelf Radio Technology: An Evaluation of Radio Technologies to Support the Marine Corps of the New Millennium*, Marine Corps Warfighting Lab, 1999.

must still be made by platoon leaders, since the Kenwood radio does not talk to SINCGARS.[31]

The Marine Corps evaluated several urban environments—street to street, exterior to interior, subterranean, and building penetration. The radios did remarkably well for their intended purpose, except in subterranean areas (see Table 3.3).

For example, in the street-to-street evaluation, 11 of 14 radios performed above a baseline subjective score (see Figure 3.2). In addition to the four urban terrain scenarios, these radios were also tested in heavy-vegetation and open-terrain environments. In particular, the ICOM models consistently scored high in most of the cases.[32]

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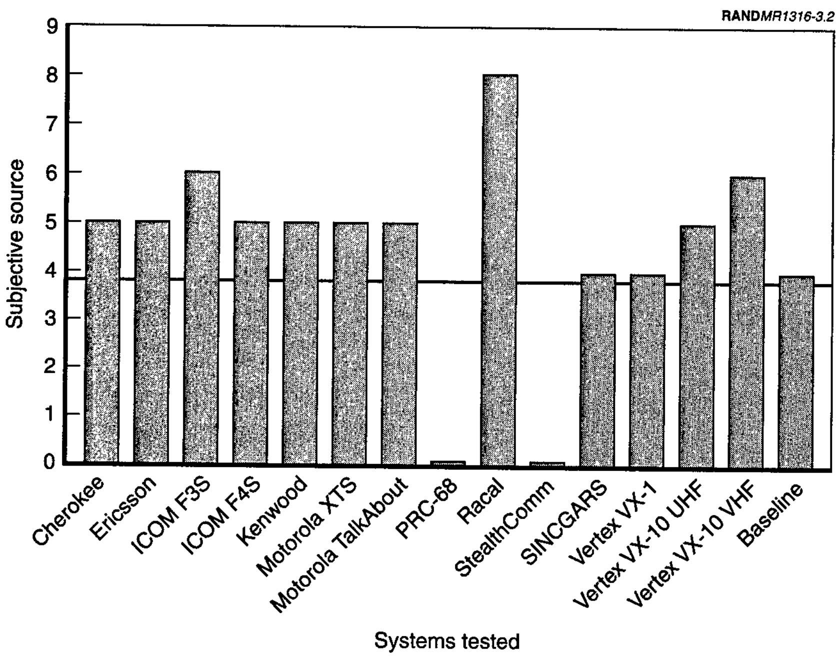
[31]Another radio that did interface with SINCGARS, called the "Isuee," was too expensive. Any commercial ISR procured in the future that is incompatible with SINCGARS will limit a squad member's ability to directly perform missions such as calls for fire.

[32]The ICOM F3S is a conventional VHF radio (136–174 KHz) and the ICOM F4S is a conventional UHF radio (400–520 MHz). It should be noted that not all the assessed systems were configured identically, which explains some of the variation in performance. For example, the Racal radio transmitted at 2 watts vice the 0.1 to 0.5 watt output used on most of the other radios. See *Commercial Off-The-Shelf Radio*



NOTE: The subjective scoring was based on a voice-quality rating given to each radio at low, medium, and high frequency. These three frequencies were recorded at three different assessment sites to produce a total of nine assessment scores, which were then adjusted and averaged to get a final score. See *Commercial Off-The-Shelf Radio Technology: An Evaluation of Radio Technologies to Support the Marine Corps of the New Millennium*, Marine Corps Warfighting Lab, p. 23. The figure is based on data from p. 24.

Figure 3.2—Urban Canyon Street to Street Performance of ISR Candidates

The Marine Corps was interested in determining the optimal frequency band across all the environments. It considered range, noise, and propagation. Range goals were met in most cases because squad offensive and defensive combat frontages are so short. Noise was a major consideration in the VHF and UHF bands because man-made machines and commercial civilian traffic produced a lot of radio frequency noise. Noise affected lower frequencies more than higher

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Technology: An Evaluation of Radio Technologies to Support the Marine Corps of the New Millennium, Marine Corps Warfighting Lab, 1999, p. 26.

frequencies. Higher UHF frequency systems also penetrated buildings more easily than VHF systems. In the end, the MCWL recommended that the ISR use the military UHF band of 225–400 MHz.[33] The Marine Corps is currently seeking to procure a Kenwood-like radio that it was scheduled to test during the September 2000 AWE.[34]

MOUT ACTD Squad Radio. MOUT ACTD evaluators used the Kenwood UHF commercial radio (460 MHz) as a surrogate during testing to determine the military utility of intra-squad communications. Since the MOUT ACTD is ongoing, the evaluation is not complete, but preliminary field tests indicate that UHF commercial radios technically work best for intra-squad communications (although these frequency ranges are very crowded). The MOUT ACTD team compared commercial radios (both VHF and UHF types) with SINCGARS and spread-spectrum radios. For the culminating AWE they will field and test a VHF radio called the ICOM F3S (3/4 watt, 136–174 MHz).

Army Land Warrior Soldier and Squad Radios. Land Warrior (LW), a program to increase the survivability and lethality of the dismounted soldier, consists of a new equipment system with components ranging from a helmet with a heads-up display to a rifle-mounted laser and infrared sight, computer/radio subsystem, a backpack, and body armor. Two Land Warrior radios, the Soldier Radio and the Squad Radio, will transmit voice and digital data between squad members. LW computers and radios will basically comprise a wireless LAN with each soldier's radio acting as a node. The network will improve a

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[33]According to the frequency allocation guidance of the Naval Electromagnetic Spectrum Center, the optimum frequency UHF band for the ISR is 225–400 MHz. Specifically, *the band that runs from 335.4–390 MHz would provide the greatest opportunity for unencumbered use worldwide.* This frequency band will provide the necessary performance and allow worldwide use. See *Commercial Off-The-Shelf Radio Technology: An Evaluation of Radio Technologies to Support the Marine Corps of the New Millennium*, Marine Corps Warfighting Lab, 1999, p. 74.

[34]The Marine Corps announced the selection of ICOM model 40008 as its ISR of choice in April 2000 on the MCWL Web site, *http://www.mcwl.quantico.usmc.mil/mcwl*. Active duty and reserve infantry battalions will begin receiving an initial package of 400 ISRs in the fall of 2000.

unit's situational awareness by allowing soldiers to constantly share GPS and inertial navigation data.[35]

All members of a dismounted infantry squad will carry the Soldier Radio, which provides radio communications in voice and a secure digital data transmission mode with a range of 1.3 kilometers. Squad leaders will also carry the Squad Radio to communicate with platoon headquarters. (The Squad Radio will be able to interface with SINCGARS SIP and SINCGARS ASIP).[36]

A new, lighter, and smaller version of LW, based on commercial-off-the-shelf technologies, was introduced in 2000 after some problems were reported with the initial LW prototype.[37] Subsequent field tests conducted by a platoon of paratroopers during the Joint Contingency Force Advanced Warfighting Experiment in September 2000 found this version 0.6 system a notable improvement.[38] Soldiers reported that LW clearly improved situational awareness during the exercises.

LW remains a work in progress. Future upgrades toward version 1.0 are planned as engineers continue to improve the overall system performance and seek to reduce its weight.

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[35]The system automatically generates and transmits regular GPS-based position update messages so that Land Warrior users can be constantly updated with each other's current location. See Joseph Fjelstad and John Murray, Ph.D., "Bringing Wireless to the Battlefield," found at *http://www.telecomclick.com,* May 2, 2001.

[36]See *Land Warrior System Specification*, A3246133M, March 12, 1998. It will also be secure (single channel frequency hopping) and operate in the 30–88 Mhz band. Also see Michael Simpson, *Military Operations in Urban Terrain (MOUT) Scientific and Technical Report (System Architecture),* Motorola Systems Solution Group, June 30, 1999.

[37]The first LW prototypes were criticized in 1999 by the media and the General Accounting Office (GAO) for cost overruns, excessive electromagnetic radiation emissions, inadequate battery power, failure to interoperate with FBCB2, and excessive bulkiness. Early tests showed that soldiers wearing the LW equipment could not lift their heads enough from the prone position and could not safely parachute with it. See John Donnelly, "Army Looks to Commercial Businesses to Save Soldier System," *Defense Week,* January 31, 2000; GAO, *Army's Restructured Land Warrior Program Needs More Oversight,* GAO/NSIAD-00-28, December 1999, p. 5.

[38]See Ron Laurenzo, "Hill Fire Lauds Land Warrior," *Defense Week*, March 20, 2000; Tanya S. Biank, "Soldiers Testing Computers in Combat," *Fayetteville Observer,* September 17, 2000.

Marine Tactical Radio. Because the Marine Corps operational concepts of Operational Maneuver from the Sea (OMFTS) and Ship to Objective Maneuver (STOM) envisage an over-the-horizon assault from distances up to 200 miles, the Corps searched for a COTS radio with a secure voice range of 200 miles and a minimum transmission data rate of 19.2 Kbps (assuming an overhead relay at 20 miles). Initially the MCWL had envisaged a search for a *single* radio to fill the capability gap noted in the battalion architecture. However, the needs of OMFTS and STOM highlighted the difficulties in locating one technology to provide both low-level squad communications the capability needed to reach 200 miles off shore. The Marine Corps did not find a terrestrial radio system that could meet these requirements today. It remains to be seen whether a new technology like the software radio might deliver this capability in the next decade.

Cellular and Satellite Phones

Satellite or terrestrial-based cellular phones do not need actual LOS between two mobile users as long as a satellite or base station is available. However, these phone systems have several drawbacks:[39]

- Cellular telephone systems require a fixed infrastructure of base stations and land lines, which could be vulnerable in a firefight.
- Neither cellular nor satellite phones have high data rates compared with VHF and UHF radios operating under the same power constraints. Satellite channels need much higher transmit power than terrestrial systems operating at the same data rate because they suffer from high path loss. Path loss is high because the path distance is long (500 to 2,000 kilometers for a LEO satellite) and the operating frequencies are high.
- They are incompatible to some degree with existing military systems.
- They have poor security and are easily jammed. Commercial firms do not worry about jamming, so they use the most efficient waveforms they can to maximize profit, sacrificing security for

[39]See Phillip Feldman, *Emerging Commercial Mobile Wireless Technology and Standards: Suitable for the Army?* Santa Monica, CA: RAND, MR-960-A, 1998.

greater spectral efficiency (information per unit bandwidth). Waveforms with high anti-jam and LPD characteristics are to some degree incompatible with high spectral efficiency.[40]

With these limitations in mind, cellular or satellite phones may nonetheless be useful in some cases, particularly in urban operations that occur in support and stability operations. Threats of enemy jamming and base station destruction may not always be present in more benign missions, such as peacekeeping. Indeed, the further one moves to the rear, the more safely one can start using commercial systems that may not be completely rugged or secure.[41] This is one reason why the services are still interested in supplementing planned military systems with some cellular or satellite phone systems.

Testing and evaluation continues. The Army's Communications-Electronics Command (CECOM) plans to demonstrate and test the Terrestrial Personal Communications System, a cellular phone system, during the coming Joint Contingency Force AWE in the fall of 2000.[42] The Marine Tactical Radio program concluded that the MUBLECOM LEO satellite phone system provided the greatest advantage in terms of capabilities, cost, availability, and technical risk. MUBLECOM was designed with military operations in mind; it provides both voice and data to the ranges required by OMFTS and STOM, and it does so with zero infrastructures on the ground. The terminal device is built to military environmental specifications, provides for voice and data encryption, has a low probability of intercept and low probability of detection waveform, and has peer-

[40]Waveform affects data rate. In general, the ability to "close a link" or achieve communications at an acceptable error rate depends not only on transmitted power, antenna gains, and signal bandwidth, but also on waveform characteristics such as error control coding and modulation.

[41]One Army general describes the reliance on commercial technologies as a sliding scale ranging from slight use for the forward warfighter, increasing to maximum use at the sustaining base. See Robert K. Ackerman, "Army Transformation Changes Force Targets for Digitization," *Signal*, July 2000.

[42]"What we want to do is to give the individual soldier one of these . . . cell phones with built-in Type One security and both voice and data capabilities," said Nita Gibson, a program analyst with the Space and Terrestrial Communications Directorate at CECOM, quoted in George I. Seffers, "Army Downsizes Battlefield Tech," *Federal Computer Week*, June 19, 2000.

to-peer as well as multicast capabilities.[43] It has an integrated positioning capability and operates in the military UHF band, thus making it immediately available for use worldwide.

UAV Relays

Adding a relay can establish a communications link between a receiver and a transmitter that are not in line of sight with each other. Establishing ground-based retransmitter sites is a common practice for radio operators in charge of setting up battalion radio nets. The relay concept could be extended to UAVs. Unmanned aerial vehicle (UAV) relays can shorten the link distance and overcome noise and LOS problems for units positioned outside in the urban canyon. At this time, neither the Army nor the Marine Corps uses VHF/UHF communication relays on UAVs.

UAV relays have been around since the Vietnam War, when over a thousand unmanned "Lightning Bug" remotely piloted vehicles (RPVs) carried out 3,435 round-trip missions. The Israeli Defense Force (IDF) pioneered the use of RPVs for radio relay platforms and subsequently used them to provide real-time battlefield updates to combat commanders.

The MCWL evaluated various UAVs to see if they could serve as relays for a marine tactical radio. Six UAVs (Altus II, Global Hawk, Gnat 750, Perseus B, Predator, and Theseus) met their performance criteria and were formally tested.[44] The Marine Corps found that UAVs offer challenges in several areas, including infrastructure, cost, and availability. For example, Global Hawk's ground infrastructure for mission planning, command and control, and communications is large (the shelter weight alone is 16,500 pounds). Environmental

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[43]The system provides Type I secure voice and data transmissions at rates up to 28,800 bps. It uses a frequency-hopping scheme to provide low probability of detection and intercept communications as well as anti-jam defense. The terminal instrument is a hand-held device that integrates GPS to provide precise positioning. The first MUBLECOM LEO satellite was launched in May 1999.

[44]The Marine Corps assumed the system had to carry a payload of at least 50 pounds. A minimum endurance cycle of one day and an operating altitude of 25,000 feet were also desired. A 24-hour endurance cycle would ease the logistics burden inherent with UAVs, and a 25,000-foot operating altitude would allow for the LOS needed for a relay covering the 200-mile range.

control units and generators add up quickly to a large footprint on the ground. The Global Hawk UAV is also a large vehicle. With a wingspan of 116 feet and a length of 41 feet, it is comparable in size to a U2. In short, current UAVs are complex machines that require skilled technical support and large logistical needs.

Smaller, tactical UAVs should be considered. The Marine Corps is looking at various UAV types, including the Dragon Drone, Dragon Warrior, and Dragon Eye.[45] Any tactical UAV capable of carrying more than 25 pounds could possibly serve as a communication relay.[46] Survivability and frequency allocation are potential problem areas for VHF/UHF UAV relays.

Attritable Relays

Man-portable relays can also overcome breaks in LOS between transmitters and receivers. Attritable relays are carried by individual soldiers and hand-emplaced as the tactical need arises in the field. DARPA is working on an attritable relay with three versions that act either as router, repeater, or geolocation beacon. The relay is activated by its own batteries, it operates autonomously, and it is used one time only, lasting up to three days.

One example is the Smart Sensor Web initiative, an effort that will evaluate acoustic, optical, weather, seismic, and magnetic sensors and relays from commercial industry. The DoD S&T office is working with the four services and DARPA and is expecting a formal solicitation in 2001. The hope is that groups of soldiers will move from building to building, placing cameras on the sides of buildings that will feed data back into a battlefield surveillance network.[47]

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[45]Dragon Drone supports the MAGTF commander for C3-related functions such as reconnaissance, surveillance, target acquisition (RSTA) missions, target ID/location, and video downlinking. Dragon Warrior is a low-cost vertical takeoff and landing (VTOL) drone. Dragon Eye is a near-expendable, man-portable, reconnaissance system for small units that the MCWL will test in December 2000.

[46]Equipping a UAV to act as a simple "bent pipe" relay (adding a transponder that simply relays a single frequency band with no waveform translation) is a possibility.

[47]See Bryan Bender, "DoD Eyes Sensors to Give 'Urban Canyon Visibility,'" *Jane's Defense Weekly*, February 16, 2000.

It is hard to imagine an operational concept that would involve the widespread seeding of attritable relays over a large area. The short lifespan and easily compromised security of these devices probably limit their usefulness to small surgical missions, such as seizing and controlling the interior of a single large building.

Chapter Four

MID- OR FAR-TERM TECHNOLOGY SOLUTIONS (3–10 YEARS)

The rapid pace of technological advancement, especially within the radio community, makes it difficult to predict when and where new technology solutions will appear. Looking forward further than three years entails much uncertainty. Moore's Law predicts a doubling in semiconductor processing power, or circuit density, every 18 months. We should expect this explosive growth to continue at that pace for another four or five years.[1] Very soon, cellular phones the size of a large coin will be mainstream technology. However, government-sponsored research is a bit more predictable because of the long lead times to actual development. Software radios, spread-spectrum techniques, array antennas, and UAV relays are a few of the more promising technologies under long-term development.

SOFTWARE RADIOS

The evolution of digital technology is transforming radios. New software radios will use software applications to perform some of the major communications functions that analog or hardware components do in current radios.[2] The design of software radios has

[1]Around 2010 some problems will arise in lithography and defining patterns. See Sharon Berry, "Technology and Human Thought Drive Future Communications Systems," *Signal*, December 1999.

[2]Other terms often used are wideband or multiband digital radios, software-defined radios, and programmable radios. However, a software-driven radio like the AN/PRC-117F is not a true software radio. In a software-driven radio, hardware components are selectively used by software. In a software radio, the waveform modulation/demodulation functions are defined in software. Analog functions such as tuning,

been enabled by rapid advances in microelectronics, including digital signal processors (DSPs), analog-to-digital (A/D) converters, application-specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs). Other than antennas, all the components of the radio system are amenable to digital implementation.

Software radios are capable of optimizing modulation, frequency, and power level to maximize performance in restrictive environments.[3] Software-programmable radio technology offers additional advantages over previous radio designs because it allows for improvements or enhancements without altering the radio hardware.

The historical background of software radios began in the late 1970s, when the Air Force began work on the Integrated Communications Navigation, Identification, and Avionics (ICNIA) system, one of the first systems to use a DSP-based programmable modem and control function. Building upon the technology developed under ICNIA, the Air Force initiated the Tactical Anti-Jam Programmable Signal Processor (TAJPSP) effort in 1989, with the objective of developing an open, modular, reprogrammable modem. The TAJPSP captured the attention of other military services and quickly developed into a tri-service programmable radio program called SPEAKeasy. The primary objective of SPEAKeasy was to develop a programmable software-defined radio core using an ad hoc radio frequency front end. The Office of the Secretary of Defense (OSD) initiated the Programmable Modular Communication System (PMCS) effort in 1997 as a continuation of the SPEAKeasy effort.[4] PMCS's effort to

filtering, demodulating, and decoding are replaced with software directing the digital equivalents. Mixers and filters can process multiple modulations spanning multiple bandwidths; the demodulation and decoding processes are programmed; and modulation and coding are usually performed using digital signal processor chips. The JTRS JPO definition of a software radio is a radio in which the digitization is at the antenna and all of the processing is performed by software residing in high-speed digital signal processors.

[3]For example, a software radio located in a room with wooden walls containing a mesh wire can automatically switch from VHF to a higher-frequency UHF signal with shorter wavelengths that are capable of penetrating the wire. If the radio is moved outside, it can switch back to a VHF signal that will propagate more effectively around buildings in the urban canyon.

[4]In 1987, acting Pentagon Acquisition Chief Noel Longuemare picked the Army to be the permanent service acquisition executive for the Programmable Modular

provide a notional software radio architecture has been superseded by the Joint Tactical Radio System (JTRS) office.[5]

No actual software radios exist at the present. DARPA is developing a software radio called the Individual Warfighter Situational Awareness System (IWSAS).

DARPA's Small Unit Operations Program and the IWSAS Radio[6]

DARPA is working on a mobile communication system that will work in restrictive terrain such as forests, mountains, urban canyons, and within buildings and tunnels. Called the Small Unit Operations Situational Awareness System (SUO SAS), it will consist of software radios, man-portable computers, relays, routers, software, algorithms, waveforms, and sensor networks, and it is intended primarily for dismounted infantry and special operations forces (but can also be used by mounted units and aircraft). A major component of SUO SAS is a new man-portable software radio called the Individual Warfighter Situational Awareness System (IWSAS). This radio will be designed to meet the technical challenges posed by restrictive terrain, multipath, fading, interference (hostile and natural), and SIGINT threats.

Communications System (PMCS), a program to develop a family of tactical radios to meet all the services' requirements. Under the PMCS approach, older, hardware-intensive radios were to be replaced with ones that have software applications for waveform generation and processing, encryption, signal processing, and other major communications functions. The Army's Future Digital Radio, the Air Force's Programmable Digital Radio, and the Navy's Digital Modular Radio programs—all of which have been pursued as separate tactical radio programs—were folded into the PMCS effort.

[5]Most of this section is based on the JTRS Web site at *http://www.jtrs.sarda.army.mil/overview/index.html.*

[6]Much of the information below is based on the presentations and reports available for downloading at DARPA's SUO SAS Web site, including "A Presentation of the SUO SAS Program to the User Community" (January 2000); "Situation Awareness System for Small Unit Operations," Dr. Mark McHenry; and "DARPA Small Unit Operations (SUO) Software Radio and Algorithm Development Program Scientific and Technical Report (Final Report) Phase II," Raytheon Systems Company (October 1999). Several companies are working for DARPA on SUO SAS, including ITT, SRI, Rockwell Collins, BBN, Atlantic Aerospace Electronics Corporation (AAEC), and Raytheon. For more information, contact Dr. Paul Kolodsky at DARPA SUO PM, DARPA/ATO, 3701 Fairfax Drive, Arlington, VA, 22203-1714.

The IWSAS is a packet-switching, non-LOS software radio that will extend the tactical internet and augment or replace FBCB2 nodes. The IWSAS is designed to operate with the upcoming JTRS, SINCGARS radios, other legacy equipment,[7] and even some commercial and emerging CDMA systems.[8] The weight goal is one kilogram, and about a half a kilogram per day in battery weight (1.5 kilograms for three days) by 2005. The range goal is ten kilometers for reliable, clandestine, 9.6-kbps communication, and 125 kilometers for "lifeline" links.[9]

The IWSAS software radio controls and optimizes all communications parameters, deciding the best frequency (from 20 MHz to 2.5 GHz), power, and data rate. Different frequency links permit nodes to network at the highest possible data rate for their environment.[10] A new adaptive modem will use multipath countermeasures to cut down on fading.

DARPA R&D plans call for an IWSAS prototype test in late FY01 and field demonstrations and final reports by June 2002. If all goes well, the earliest these radios could be fielded is 2004.

Joint Tactical Radio System

The Department of Defense wants to migrate to a single family of tactical radios built with a common architecture known as the Joint Tactical Radio System (JTRS). The JTRS is a family of multiband, multimode, tactical software radios capable of generating multiple

[7] Such as American or allied radio equipment that is analog, push-to-talk, and operates FM in the 30–88 MHz band or AM in the 225–400 MHz band.

[8] According to the October 1999 Raytheon report, the SUO/SAS modem has several programmable parameters that can be set appropriately to handle the commercial cellular waveforms and the DISA satellite communications waveforms. This includes emerging "Third Generation" CDMA standards—W-CDMA and CDMA 2000—that are still evolving, and component providers are already designing chips to support these standards. One exception is Globalstar, because it uses a carrier in the range of 2.5 GHz for the downlink, which is outside the proposed SUO/SAS system range.

[9] Lifeline means the signal is nonsecure and operating at a minimal data rate.

[10] The transmitter sends out a special reservation request to sense link conditions first, then it optimizes data rate, coding rate, and power for the best possible data rate (up to 4 Mbps) on each subsequent packet transmission.

waveforms between 2 and 2000 MHz (initially), transmitting voice, video, and data. Jets, helicopters, tanks, and soldiers will all have versions tailored to their needs.[11]

By building upon a common open architecture, JTRS will improve interoperability by providing the ability to share waveform software between radios. An industry consortium led by Raytheon Systems Company has been contracted to develop the architecture for JTRS, and the services will be responsible for procuring their own radios.[12] The goal of the JTRS Joint Program Office (JPO) is to migrate today's legacy systems to systems compliant with the JTRS architecture.[13] No JTRS software radios actually exist yet.

A number of important technical challenges must be addressed in developing JTRS. These challenges arise because many of the JTRS requirements can only be met by using state-of-the-art, and in some cases future, technologies. For example, the development and implementation of mobile networking protocols is a technical challenge to the JTRS effort. The new warfighting paradigms, such as *Joint Vision 2010,* emphasize mobile, flexible networks that automatically adapt to the warfighter's needs. These paradigms require mobile networking capabilities significantly beyond what is possible with currently fielded technology. JTRS networking protocols must support a variety of services, including automatic neighbor and link-quality discovery, automatic network reconfiguration, quality-of-service guarantees, precedence and priority marking, and the automatic routing and relaying of traffic.

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[11]Civilian organizations such as local fire, police, and medical units also hope to use JTRS radios.

[12]See Chris Strohm, "Pentagon Mulling Transfer of Joint Tactical Radio Program to Army," *Inside the Army*, June 12, 2000.

[13]The JTRS requirements are promulgated in the JTRS Operational Requirements Document (ORD), itself derived from the JTRS Mission Needs Statement (MNS). These documents place stringent operational requirements on JTRS implementations, presenting significant technical challenges to the JTRS developers. Since no single implementation is capable of meeting all the ORD requirements, JTRS is envisioned as a family of radios based upon a common architecture. In view of its potential applicability across a wide range of communications devices, this architecture is known as the Software Communications Architecture (SCA). In addition to its use in JTRS applications, the SCA has been advocated as a standard for use in commercial applications by the Software Defined Radio (SDR) Forum. The SCA is currently under development, based on an initial baseline SCA framework established by the JTRS JPO.

According to the Defense Science Board, there are "no technical show stoppers with respect to developing the JTRS." In fact, they believe acquisition efforts by the Joint Program Office (JPO) should be speeded up, and prototypes are feasible in 12 to 14 months (from February 2000).[14] Reducing the number of legacy waveforms this new radio must support will also lower the cost. Current plans to force the JTRS to address 37 different legacy waveforms limits the application of digital information transfer in future military operations.

ULTRA-WIDEBAND (UWB) SIGNALING[15]

One way to reduce fading is through new signaling techniques. Ultra-wideband (UWB) signaling is a promising new technique that is relatively more covert, more jam-resistant, and more resistant to multipath interference.[16]

Ultra-wideband signals are spread across a larger band of frequencies than is required for normal narrowband transmission.[17] As a result, the average power or amplitude at any given frequency is virtually indistinguishable from background noise. This makes UWB signals more covert than narrowband signals. The wide operating bands of UWB systems make it difficult for jammers to distribute enough energy across all used frequencies (up to several GHz in some cases). Ultra-wideband signals also do not fade as much because they are time-modulated rather than amplitude- or frequency-

[14] *Tactical Battlefield Communications*, Defense Science Board Task Force, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, February 2000, p. D-7. Another estimate states that the first JTRS radios could be in use in two years; see Daniel G. Dupont, "Reengineering the Radio," *Scientific American*, July 2000, p. 18.

[15] A waveform is ultra-wideband if the fractional bandwidth (bandwidth in Hertz divided by the center frequency in Hertz) exceeds 25 percent. By comparison, narrowband waveforms (most communication waveforms are narrowband) have fractional bandwidths less than 1 percent. This commonly accepted definition is taken from comments by Phillip Feldman, Communications Engineer at RAND, 1998.

[16] UWB also has other useful applications, such as radar imaging of objects buried beneath the ground or behind walls.

[17] Ultra-wideband signals use a form of spread-spectrum processing called direct sequence spread spectrum. Another spread-spectrum technique is frequency hopping, which SINCGARS radios use.

modulated. UWB radio pulses are of such short duration that the reflected versions of the signal do not cause destructive interference.[18]

At least one commercial firm has produced a hand-held wireless UWB radio capable of sending voice and digital data. Time Domain's "Marine Corps radio"[19] is a covert LPD/LPI radio with a center frequency of 2 GHz, a range of at least 1.2 kilometers, and multipath immunity.[20] Engineers are working to reduce size, weight, and power consumption, increase range, and improve the in-building performance of the core components of this radio (the ASICs). The technology was demonstrated during field tests at the Marine base at Quantico, Virginia, in October 1997; in early 2001 a much more efficient and smaller version of Time Domain's ASICs will be available for testing.[21]

Several UWB challenges need to be addressed. Existing regulatory mechanisms are inadequate for UWB systems. There are, for example, large numbers of so-called restricted bands; the FCC will not license transmitters that generate any power in these bands. These regulations are not a problem for the federal government, which is exempt, but they are an impediment to the success of commercial applications. Large numbers of UWB systems in a given area may also cause interference problems for narrowband systems because of the increased noise ("spectrum pollution") they produce. Finally, there are difficult antenna design problems to be worked out.[22]

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[18]See William B. Scott, "UWB Technologies Show Potential for High-Speed, Covert Communications," *Aviation Week & Space Technology*, June 4, 1990.

[19]Also called the Ultra Wideband Technical Electronic Device (UTED).

[20]Based on telephone comments by Glenn Morris, Radar Operations Manager, Time Domain, August 3, 2000.

[21]According to Adrian Jennings at Time Domain, a research tool called the Pulseon Application Demonstrator Mark II will be ready for testing in the first half of 2001. Based on telephone comments, August 8, 2000.

[22]Time Domain considers its antenna designs proprietary information and will not release information on them to the public.

ARRAY ANTENNAS

Array antennas mitigate the effects of fading by using a countermeasure called diversity reception.[23] Multiple antenna elements are mounted at the receiver end so that several separate, independently fading signal paths are established between the transmitter and receiver. Almost all of the multipath variation is removed by first separating out and then later combining the independent paths, with each path weighted by its received signal power.

Array antennas are steadily being reduced in size. Right now the smallest array antenna is vehicle mounted, but it is foreseeable that a man-portable size will be available in the next eight years or so.[24] The physical size of an array antenna is dictated by the wavelength of the signal, because each of the elements of the antenna are typically separated from each other by at least one half the signal wavelength.[25] This means that building a hand-held or man-portable VHF and UHF array antenna may not be practical. However, man-portable array antennas using higher frequencies (which have much shorter wavelengths) are possible, such as SATCOM and commercial cellular phone applications. If this technology is successfully developed, it will contribute significantly to the military application of commercial wireless LANs.

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[23]Independent fading paths can be achieved by separating the signal in time, frequency, space, or polarization. Space diversity is the most efficient of these techniques. See Section 2.1.5.1 in Goodman et al., *Evolution of Untethered Communications*.

[24]One type of array antenna is an active array, in which the individual antenna elements are controllable. Add a processor, and you have an adaptive-array antenna, a "smart antenna" that can change the shape and direction of its transmission beam and is ideal for mobile users. The key technical challenge to developing a man-portable adaptive-array antenna is the size and cost of the RF and signal-processing technology.

[25]"Because the wavelength is inversely proportional to frequency, antenna arrays can be mounted on hand-held units when using super high frequencies (above 10 GHz) but not when using frequencies below the 1-GHz range." Goodman et al., *Evolution of Untethered Communications*, Section 2.1.5.1.

FUTURE RELAY PLATFORMS

The section "UAV Relays" in Chapter Three described how communication relays on UAVs can overcome line-of-sight problems between two tactical radios on the ground. The conclusion was that sophisticated communication relays on UAVs were unlikely in the near term. The prospects for the next decade are brighter.

DARPA is running a program called Airborne Communications Node (ACN) that aims to develop a communications and signals intelligence (SIGINT) payload for UAVs. The idea is to use an airborne infrastructure of ACN-equipped UAVs to provide wireless communications for mobile tactical units dispersed across wide areas. The communications payload of the ACN will be scalable and modular, so that it may be lightened to 25 pounds, small enough to fit on a tactical UAV like the Shadow.[26] Notional designs also call for a 100-pound package for the Predator and a 900-pound package for the Global Hawk.[27]

ACN will support VHF and UHF combat net radios as well as S- and Ku-band SATCOM radios. ACN will also have crossbanding capability—in other words, it will be able to receive a VHF signal, then translate and relay it to a satellite. In effect, tactical radio users will have access to SATCOM without having to use a SATCOM terminal.[28]

DARPA plans to complete development of the critical technologies at the component level and mature the payload architecture to a preliminary design in FY01.[29] By FY03, DARPA plans to deliver a "critical

[26]Of course, a reduction in size also means a reduction in capability.

[27]One approach to ACN is to remove the synthetic aperture radar sensor and EO/IR sensor from Global Hawk, which frees up 900 pounds of payload and 6 kW of power for the communications package. The package would contain a 48-inch Ku-band and a UHF SATCOM antenna. At an altitude of, say, 60,000 feet, the communications footprint radius would be 150–200 miles. The ACN could act as a gateway between users who cannot communicate directly due to line-of-sight limitations. Christopher C. Bolkcom and Joseph A. Tatman, "US Military R&D," *Jane's Special Report*, Alexandria, VA: Jane's Information Group, 1997.

[28]Based on comments and presentation by George Duchak, telephone interview, August 25, 2000.

[29]See a brief description at *http://www.darpa.mil/ato/programs/can.htm.*

design," which the services could theoretically use to build a vehicle. Production and/or further testing could occur by FY05.

Chapter Five

CONCLUSIONS

As U.S. military forces modernize and rely more on information systems, the need for radios that transmit that information at the lowest tactical level is becoming more critical. Both technology and doctrine will have to adjust to meet the increasing demand for bandwidth on the battlefield.

The pessimistic outlook is that non-line-of-sight transmission through obstacles does not exist, nor does a breakthrough appear imminent. However, the microelectronic revolution of the 1970s and 1980s is beginning to pay some dividends for wireless communication. One promising technology is the software radio, which will offer unprecedented flexibility and interoperability to the dismounted infantryman fighting in the urban canyon. If the promise of software radios can actually be delivered, the next generation of tactical radios may actually be able to keep up with commanders' growing demand for information. Commercial radios are improving command and control at the lowest tactical levels, where the need for intra-squad and inter-squad communication can now be satisfied. Other military-unique requirements of the mobile infantryman will demand government-funded solutions. UAVs and attritable relays offer ways to add links to get around obstacles. New ways to process signals such as UWB will allow us to improve upon today's capability.

The fact that our current doctrine on solving communication problems in urban operations is so meager forces us to ask whether new and innovative TTPs can be used to satisfy the warfighter's C3 needs. Relying on wireless communications for improved situational awareness means that commanders and staff officers will have to know how to avoid fading and path loss. Updating our field manuals with some of the lessons learned from commercial engineering studies and military experimentation is a useful start.

Over the next three to four years there is little expectation that wireless communications will be significantly improved. Incremental improvements are possible in the next decade with the emergence of potential new technologies such as the software radio and new waveforms. One should remember, however, that communication problems have always existed and will continue to exist, not only because of the physical nature of urban terrain but also because of the chaotic nature of war. In combat, antennas are shot off or broken, radios are damaged by explosions, and radio operators are killed by snipers. Soldiers must constantly adapt to changing levels of situational awareness. No matter how many new technologies we add, soldiers and marines will always need to train with a baseline set of command and control TTPs that work in the absence of wireless communications.

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