

COMMUNICATIONS, RADAR AND ELECTRONIC WARFARE

Adrian Graham

Independent Consultant, UK

 **WILEY**

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Preface

I have been fortunate during my career to work with a wide range of designers, managers and operators in the communications, radars and electronic warfare fields. During that time, I have had the opportunity to provide a technical input into their activities via providing consultancy, design of new systems and techniques and training courses at a range of levels. One of my main tasks has been to develop methods suitable for operators based on highly technical materials. This is not always an easy task; it can be difficult to present complex material in a form that does not require the operators to be experts themselves. This is not to denigrate in any way the abilities of operators. They have to perform excellently in their roles, often in very difficult circumstances, and they simply do not have the time to commit to working out how to convert theory into practice in the field. Thus, much of my time has been spent working out ways to simplify practical methods of applying theory for the widest possible range of circumstances. I have tried to adopt the same approach in the preparation of this book. It is also my own personal opinion that there are two types of information available about these subjects. One is highly theoretical and beyond the needs of most workers in the field. The other is slightly too simplified, omitting vital information without which it is impossible to really understand the subject. In this book, I have tried to bridge the gap between these two opposing approaches. I hope I have succeeded.

During my time working with operators, engineers and managers, I have identified a number of specific areas where I believe understanding is limited throughout the industry. These are the areas I have tried to emphasise in this book, and the ones I spend most time on when I design and run training courses. I have also tried to bridge the terminology gap between workers in the three areas covered by this book. Often, there is misunderstanding between these people when they meet, simply based on terminological and learned approaches when they are in fact talking about the same things. I have deliberately used a mix of terminology to blur these lines. I have in some cases also opted not to use terminology used by one group that may not be understood by others. This is often service or allegiance based, and again they can act to cause confusion where the terminology is not shared by others; this book is, after all, aimed at a worldwide market.

I have provided some references and further reading after most of the chapters. I have tried to choose reading material that is not too theoretical such as academic papers where possible. Where no references are provided, the material is based on my own experience.

As the reader can imagine, I could not have created this book without the input of a vast array of input from other people over the years. There are a few in particular I would like to thank. Since they are still working in the field, particularly in EW, most would rather not be identified. However, both they and I know who they are.

I would also like to thank my long-suffering project editor at John Wiley & Sons, who has had to wait far too long for this manuscript. The support given to me by my equally long-suffering special friend Leanne, my brother Jim and my mother Brenda has also been invaluable. Finally, I would like to thank Alan Smith, the best friend anyone could hope for, who has supported me in many ways during the writing of this book and who, when times have been tough, has comforted me with cider.

Adrian Graham

Glossary

AAM	Air to Air Missile
AGA	Air-Ground-Air, usually relating to communications
AGC	Automatic Gain Control
ARM	Anti-Radiation Missile
AM	Amplitude Modulation
ASM	Air to Surface Missile
AOR	Area of Responsibility; area within which a military force element works
APOD	Air Point of Departure
AWGN	Average White Gaussian Noise (a flat response over the band of interest)
Antenna	Device to convert electrical energy to RF energy and the converse
Backhaul	Network used to trunk traffic from a mobile system
Battlespace	Term used to define the battle area, which extends beyond physical bounds (the battlefield)
BER	Bit Error Rate
BSM	Battlespace Spectrum Management (plan); military spectrum plan
Burn-through	Overcoming jamming by the robustness of the target link
CDMA	Code Division Multiple Access
CEW	Communications Electronic Warfare
C/I	Carrier-to-Interference ratio (dB)
CIWS	Close In Weapons System
CME	Coronal Mass Ejection; an eruption on the surface of the sun
COMINT	COMmunications INTelligence
CONUS	Continental United States (of America)
CNR	Combat Net Radio
Combiner	Device to combine more than one radio signal into a single antenna
Connector	Physical electrical connector for RF cables and systems
COTS	Commercial Off The Shelf; standard systems available to buy
CW	Continuous wave; as opposed to periodic pulsed transmissions

Diplexer	Passive device to combine radio signals into a single antenna without loss
dBd	Loss or gain reference an ideal dipole antenna
dBi	Loss or gain reference an ideal isotropic antenna
DEM	Digital Elevation Model
DF	Direction Finder/Finding
DME	Distance Measuring Equipment (aeronautical)
Downlink	(1) Link from a terrestrial fixed radio station to an associated mobile station (2) In satellite systems, from satellite to Earth station
DRDF	Digitally Resolved Direction Finding
DTM	Digital Terrain Model
DVOR	Digital VHF Omni-directional Radio ranging (aeronautical)
EA	Electronic Attack (EW)
ECCM	Electronic Counter-Counter Measures
EIRP	Effective Isotropic Radiated Power, versus a perfect isotropic antenna
EHF	Extra High Frequency (30–300 GHz)
ELF	Extra Low Frequency (0.3–30 kHz)
EMCON	EMission CONtrol; controlling RF emissions to avoid exploitation by the enemy
EM	Electro-Magnetic
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EMP	Electro-Magnetic Pulse; damaging RF energy from a nuclear weapon or EMP weapon
EOD	Explosive Ordnance Demolition
EORBAT	Electronic Order of BATtle
EP	Electronic Protection (EW)
ERP	Effective Radiated Power, normally versus a dipole antenna
ES	Electronic support (EW)
EW	Electronic Warfare (EW)
EW	Early Warning (alternative meaning, depending on context)
FAA	Federal Aviation Authority
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FEBA	Forward Edge of Battle Area
Feeder	RF cable used to connect RF components together
FFZ	First Fresnel Zone
FH	Frequency Hopping
Filter	Device to condition an electrical signal in the spectral domain
FM	Frequency Modulation

Force Element	Military assets assigned to a specific task
FSL	Free Space Loss; spreading loss only (dB)
GCHQ	Government Communications Headquarters (UK)
GCI	Ground Controlled Intercept
GIS	Geographic Information System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
Hardkill	Physical destruction of assets
HF	High Frequency (3–30 MHz)
HME	Home Made Explosive
HND	Host Nation Declaration; response to an SSR
HUMINT	HUMAn INTelligence; informants
ICAO	International Civil Aviation Organisation
ICD	Improvised Chemical Device
IED	Improvised explosive device
IF	Intermediate Frequency
IFF	Identification Friend or Foe
IID	Improvised Incendiary Device
ILS	Instrumented Landing Systems
IMINT	Image INTelligence
IND	Improvised Nuclear Device
IMP	Inter-Modulation Product
IRD	Improvised Radiological Device
IRF	Interference Rejection Factor
ITU	International Telecommunications Union
JRFL	Joint Restricted Frequency List
J/S	Jamming to Signal ratio
JSIR	Joint Spectrum Interference Resolution (process) – US interference resolution method
JSR	Alternative form of Jammer to Signal Ratio
LIDAR	LIght Detection And Ranging; high resolution terrain data capture method
LF	Low Frequency (30–300 kHz)
MASINT	Measurement And Signature INTelligence
MBITR	Multi-Band Inter/Intra Team Radio
MCFA	Most Constrained First Assigned; frequency assignment approach
MF	Medium Frequency (300 kHz–3 MHz)
MGRS	Military Grid Reference System
MLS	Microwave Landing System (aeronautical)
MOTS	Mostly Off The Shelf; standard systems that are partially modified
MSR	Main Supply Routes
NDB	Non-Directional Beacon (aeronautical)

NFD	Net Filter Discrimination
NSA	National Security Agency (USA)
OP	Observation Post
OPTEMPO	Level of operational intensity; OPerational TEMPO
ORBAT	ORder of BATtle
OTHT	Over The Horizon Targeting
PIRA	Provisional Irish Republican Army
PM	Pulse Modulation
POD(1)	Probability of Detection
POD(2)	Point of Departure; air (also known as APOD) or port used in military operation
POI	Probability of Intercept
POJ	Probability of Jamming
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PSK	Phase Shift Keying
PSO	Probability of Successful Operation; the likelihood that a given link will work
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
Radio System	Any system that uses RF channels in order to function, including communications, navigation, radars, jammers etc
RCIED	Radio Controlled Improvised Explosive Device
RF	Radio Frequency, as in radio frequency device
SAG	Surface Action Group; naval force element
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SHF	Super High Frequency (3000–30 000 MHz)
SHORAD	Short Range Air Defence system
Short sector	A region where the nominal signal level will not change, but within which the instantaneous level changes due to fast fading
SINAD	Signal In Noise and Distortion
SMM	Simplified Multiplication Method; method of assessing interference from multiple interferers
SNR	Signal to Noise Ratio
Softkill	Disruption or destruction by non-lethal means
SOP	Standard Operating Procedure
Spoofing	A radiating system pretending to be a different system to fool enemies
SSM	Surface to Surface Missile
SSN (1)	Sun-Spot Number (HF)
SSN (2)	Nuclear Submarine (force element)

SSR	Spectrum Supportability Request; request to a host nation for spectrum
TAPS	TETRA Advanced Packet Service
TEL	Transporter, Erector, Launcher – a missile launch platform, usually a large vehicle holding a tactical land or coastal surface-attack missile
TETRA	TErrestrial Trunked RAdio
UGS	Unattended Ground Sensor
UHF	Ultra High Frequency (300–3000 MHz)
UN	United Nations
Uplink	(1) Link from a mobile station to a fixed terrestrial radio station (2) In satellite, from Earth station to satellite
UTM	Universal Transverse Mercator; a data projection
VHF	Very High Frequency (30–300 MHz)
VLF	Very Low Frequency (3–30 kHz)
VOIED	Victim Operated Improved Explosive Device
WGS84	World Geodetic System 1984; geographic datum used by GPS

Part One

Basic Theory

1

Introduction

1.1 The Aim of this Book

This book looks at the subjects of radio communications, radar and electronic warfare. The aim is to provide the reader with a mixture of theory and practical illustrations to explain the way in which these systems are used in practice. The book is aimed at operators, designers and managers operating in these areas. It is designed to provide a detailed overview at a level suitable for this audience. This means that the intention has been to provide explanation of complex theory in as simple manner as possible, and to link the theory to real life as far as possible. One of the main reasons for writing the book is that there is a large body of very in-depth, complex works that are beyond the grasp of the average reader. There are also works that provide simple overviews but without introducing the necessary background theory. Hopefully, this book provides a middle way between these two extremes.

The book has been split into two main sections; theory and practice. The idea is to lay the necessary theoretical groundwork, and then to spend more time in the main, practical part of the book identifying the operational effects of the theory when applied. In this way, the book is designed to bridge the gap of theory to application in a way that makes sense to communications and electronics operators, system designers and managers.

One aim in writing the book has been to provide as compact knowledge as possible in each section. Thus rather than having to find an earlier reference, in some cases the theory has been re-introduced, and some diagrams replicated, in some of the practical sections where they are explicitly required. The reader can therefore easily dip into individual sections and get most of the information without having to go back to the theoretical sections. Thus, those whose interest is primarily for radar for example, the book has been split up in such a way as to collate the relevant information into readily located sections. *To make the book more readable, I have used the term 'radio' to mean any system that uses the RF spectrum, including radars and navigation system.*

The main focus of this book is on the Radio Frequency (RF) part of the system. This is the part between two antennas in a link. However, in order to make practical use of this, it is necessary to examine the parts of the system that are essential to allow the construction of an accurate radio link budget. This means every step from the radio output from the transmitting radio to the output of the receiving radio. The focus will be on those aspects over which operators and developers have some control, such as selected frequency, antenna, location and system configuration.

To those new to the field, I would recommend reading all of the theory section and then the sections relevant to the reader's area of work. More experienced readers may choose to go to the sections that are relevant to their work, with the theoretical sections being available as an easy reference when required.

My hope is that this book finds resonance with those involved in this topical and important area and that it helps such people to improve the state of the art of mission planning and simulation of real-life scenarios.

1.2 Current Radio Technology

1.2.1 Introduction

No one can be unaware of the pervasive nature of radio systems in the modern world. The rise of mobile phone systems has been phenomenal, and this has been matched by other recent developments that have improved the links between mobile phone masts (normally called 'backhaul'), provision of internet access via WiMax and other systems, improvements to broadcast systems brought about by new digital services, and worldwide navigation via GPS.

In the military sphere, similar new technologies have been used to extend system ranges, improve security and to provide information throughout the Battlespace. However, this description could equally be used to describe the developments of civilian systems as well. Increasingly, civilian equipment is becoming more frequently used by armed forces and particularly by insurgents. In some cases, the increasing capabilities of commercial systems are also being exploited by even the most well equipped armies because they are better than their own systems and they can be fielded very much more quickly than new military systems.

Because of these factors, this book includes analysis of modern civilian services as well as military ones. Such systems may be used to provide emergency or short-term communications for military operators, and are also increasingly of interest to electronic warfare operators as legitimate targets since they are used by the opposition. As we will see in the next few pages, the historically distinct fields of military and civilian use of the radio spectrum are in many ways merging into a single set of requirements, at least at outline level.

This section will look at military, civilian and joint technologies. It will look at the commonalities and contrasts and draw conclusions as to how they can be

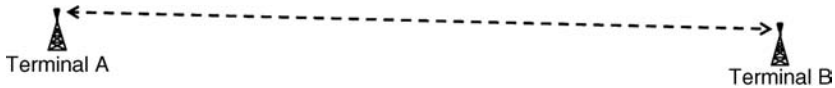


Figure 1.1 The basic radio link between two terminals. These can be fixed, static locations or can be dynamic links where the terminals move and the link is only present during short communications.

managed by military and other organisations for communications and electronic warfare purposes.

First, we will take an overview of the different types of radio system as they appear to their users.

The simplest configuration is that of a radio link between two defined locations as illustrated in Figure 1.1. In this case, there are two locations with radios, which act as terminals to the link. The arrows at both ends indicate that the link is bi-directional, sending voice or data from either terminal to the other. This type of link is known as a ‘point-to-point’ or abbreviated to ‘point-point’.

Links can be permanently established between two terminals, such as in fixed microwave links, or they may be temporary, such as between a mobile phone base station and a mobile subscriber or between two tactical groups. Single links can be combined into networks as shown in Figure 1.2. The structure shown is typical of the traditional military command and control model (this is a generic model, not built around any particular country’s organisation). In this case, the view is in plan form (from above). Each terminal is a black dot and each link is a solid black line. Note that in this model, not all terminals are linked to each other. None of the individual echelon levels (battalion, regiment, brigade, division) talk directly to each other; instead they have to go to a higher level of command until direct links are provided. The network structure is therefore hierarchical.

Networks of point-point links can also take many other forms, ranging from the instantaneous configuration of Personal Role Radio (PRR) networks covering a few hundred metres to national microwave networks.

Apart from point-point radio systems, the other main type of communication system is the mobile network as shown in Figure 1.3. In this case, there is a single fixed base station and a number of mobiles moving through the coverage area, shown as black squares with a track showing where they have been.

It is worth noting that at an instant in time, the mobile network can be described as a point-multi-point network (one base station serving a number of users). Mobile networks normally consist of many base stations to provide coverage over a wide area, for a very large number of subscribers.

Mobile radio systems are often trunked, so calls between parts of the network can be passed to over parts of the network. Figure 1.4 shows an example of a simple trunked network. Fixed base stations are shown as black circles. The coverage of the base stations is shown in grey. The main trunks are shown as thick dotted lines, with feeder

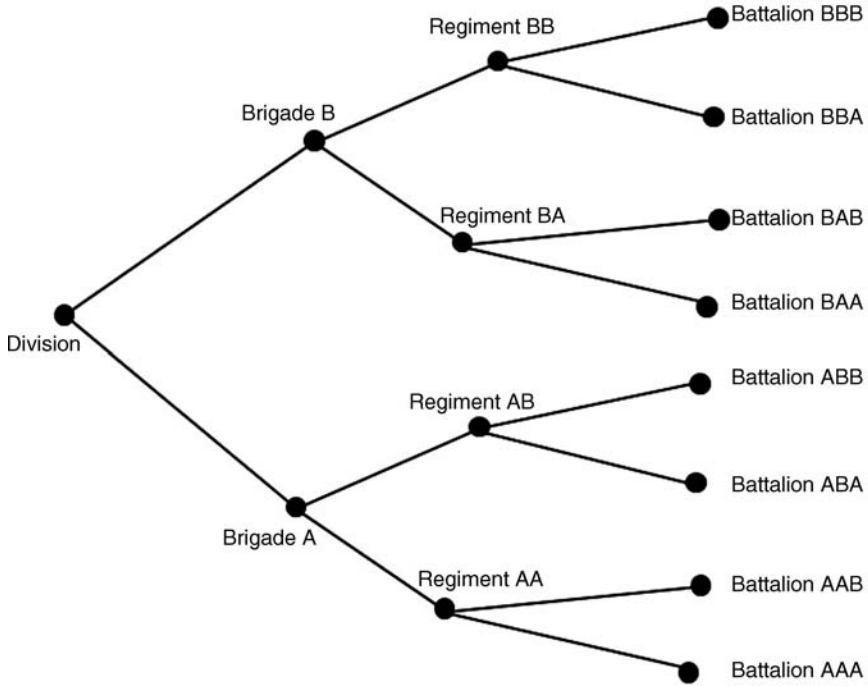


Figure 1.2 A typical hierarchical military command and control radio network. The network design is deliberate so that it supports the way the command structure works.

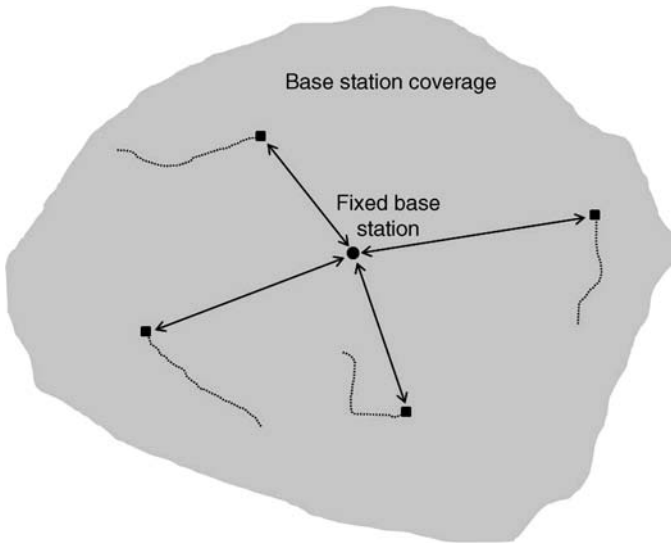


Figure 1.3 A simple mobile network.

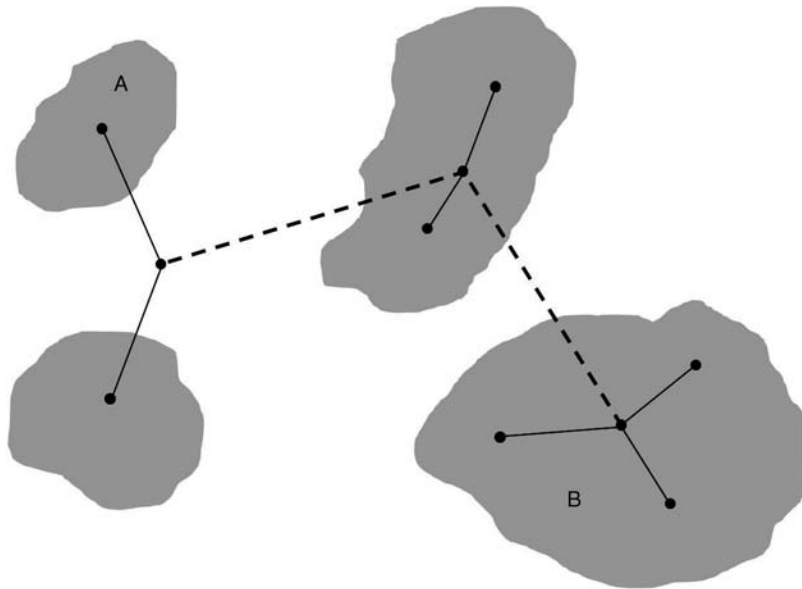


Figure 1.4 A trunked radio network providing mobile coverage to subscribers in the coverage area shown in grey. The thick dashed lines show main trunks and the thin solid lines show trunks between out-stations and the main trunk terminals. This type of network is used in military deployments and also for PMR and mobile phone networks.

links shown in thin solid lines. The trunks provide a link between the different parts of the network, so a caller originating at point A can talk directly to a mobile at point B.

Radar systems provide the means to detect and localise aircraft, ships and battlefield systems. In many cases, such as blue-water maritime scenarios and high altitude aircraft, coverage from radar systems will be circular in form, out to a maximum range for a given type of target at a given altitude. However, in many other cases, radar coverage will be limited by the environment as illustrated in Figure 1.5. This shows the coverage of ship air search radar looking for low altitude targets. Over the sea (left hand side), coverage is circular but over the ground (right hand side) the coverage is limited by hills and ground clutter.

Radars can also be used in networks to provide wide area coverage by a number of linked radar stations. This is shown for a naval group in Figure 1.6, where the composite network coverage from the combined ships is shown in grey.

We will see many more examples of radio systems during the rest of the book.

1.2.2 Military Communications

Military communications have traditionally evolved to meet perceived needs for the battlefield. Since the end of the Second World War, the Western and Eastern blocs

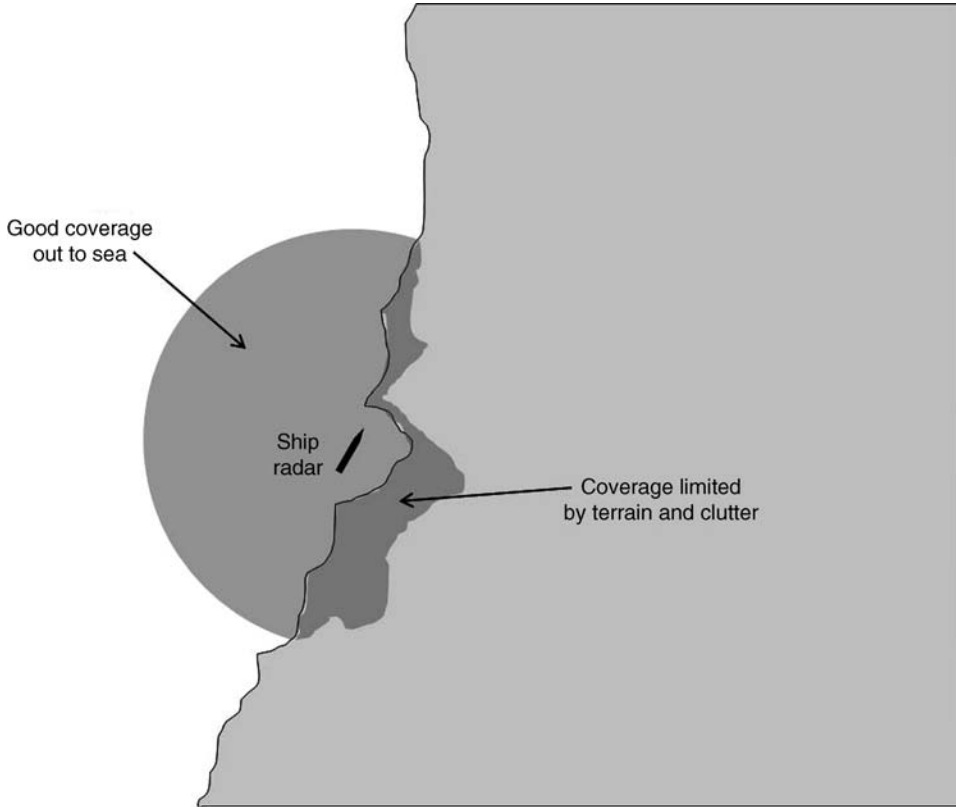


Figure 1.5 Illustration of a ship using radar close to shore. The coverage of the radar over the land is limited by the effect of terrain such as hills and also by radio clutter, which adds noise and obscures genuine targets.

focused entirely on the possibility of a major European or World war that would be essentially nasty, brutish and short.

The major characteristics of this scenario are worth analysis to see how they influenced radio network architecture and radio design. These characteristics included:

- It would take place in a known environment. This was true for the land, air and naval conflict. Although there was the possibility of some variation from the central script, actions and responses were well practiced and known.
- It would be of particularly high intensity. This would have been particularly true in the Forward Edge of Battle Area (FEBA). This would have meant congested airwaves, little time to detect and assess radio targets of interest and a very difficult spectrum management regime. In practice, this meant that dynamic spectrum