



# PERSONAL COMMUNICATIONS SYSTEMS (PCS)

## - THEIR INFLUENCE ON THE BATTLEFIELD

This is one of a number of Information Sheets, on emerging technologies to inform the Department about topics that are of importance to defence, produced by a panel comprising some of the UK's leading experts.

### The Communications Technology Panel

In addition to MOD staff led by the Chief Scientific Adviser (CSA), the Computing Technology Panel comprising UK and world leading scientists and engineers from industry and academia.

Professor Peter Kerstein is Professor in the Department of Computer Science, University College London. He is a Fellow of the Royal Academy of Engineering and his current research interests involve high-speed networks and networked multimedia.

David McKenzie is Director of Emerging Business for IBM EMEA. His responsibilities include evaluating new technologies for their applicability as part of e-business solutions for customers and partners. His previous role was Director of Pervasive Computing for IBM EMEA.

Professor John O'Reilly is chief executive of the Engineering and Physical Sciences Research Council (EPSRC) and previously held the Chair of Telecommunications at University College, London, where he was Head of the Department of Electronic and Electrical Engineering.

Paul Stein is Managing Director of Roke Manor Research Limited. His areas of interest cover both commercial and military communications systems for fixed, cellular and broadcast technologies. He is a member of the Defence Scientific Advisory Council.

Professor Michael Underhill is Chairman of Toric, a spinout company from the University of Surrey where he remains a part-time Professor of Electronics. He is a Fellow of the Royal Academy of Engineering. His current research interests cover phase noise reduction, electrically small and smart antennas, complexity and systems engineering.

## INTRODUCTION

Historically, new developments in communications systems have oscillated between wired and wireless. Early initiatives in Morse telegraphy and the wired telephone subsequently gave way to Marconi's wireless telegraphy and then to voice. After the Second World War fixed wireless systems led the way providing higher capacity terrestrial and satellite radio links. Later networking led to the advent of the Internet and the interconnection of computers. Cellular communication systems were also developed, but these two communities largely stayed apart.

Now, for the first time, networking and radio are getting together to meet the desire for high capacity, mobile and flexible personal communications systems (PCS) - thereby providing communications on the move and enabling new concepts like pervasive computing (see the Information Sheet on Computing Technology for Defence). This information sheet explores some of these exciting new developments and how they affect the future of military communications.

## THE IMPORTANCE OF COMMUNICATIONS TO THE MILITARY

Communications via radio, cable or optical fibre pervades all aspects of military operations. Communication systems provide the vital conduit between one computer and another to ensure the distribution of command and control, intelligence and other information.

Communications are the glue that cements military operations. Without a functional communications system virtually all modern wartime and peace keeping activities would quickly grind to a halt and knowledge superiority would be impossible.

In order to maintain information dominance, military communications must be maintained when and where needed. What makes Military Communications systems different from civil systems is that they have traditionally been designed to resist geo-location, jamming and other electronic warfare (EW) threats [see box on Electronic Warfare (EW)]. As a separate issue they must provide end-to-end message security in order to maintain confidentiality. The network must also be robust to physical disruption; architectures employing a single critical communications node, such as a computer or radio station, have to be avoided if possible. Also many military communications have to be maintained on the move, perhaps between fast moving vehicles such as aircraft or perhaps between command posts and moving troops. Meeting these latter requirements significantly complicates radio system architectures and information flow rates compared to those that are achieved in civilian systems.

Against this background of military requirements are the products offered by civilian telecommunications

companies and their research and development (R&D). It is estimated that the UK civilian telecommunications research investment in 2001 was around £700M, a number that dwarfs the military spend of £22M. So future developments in military communication systems will be driven by developments in the civilian world.

Can civilian communication systems meet the military requirements directly, or should new military communications systems try to harness the underlying civilian technology rather than the systems? Where are the military communications niche markets which will not be supported by civilian ones? Where should the military communications R&D be focused?

### Electronic Warfare (EW)

A well-designed military communications system aims to be resilient to disruption by the enemy. Physical attack is an obvious strategy but more sophisticated approaches collectively known as electronic warfare (EW) are possible. EW includes jamming by enemy signals. It also includes interception of the signal to ascertain that messages are being sent, to analyse the characteristics of the messages or perhaps to even decode the messages. In addition it also includes direction finding of signals to determine the location of the transmitter. The military communications engineer and EW specialists can be viewed as competitors in an ever-changing world.

## THE CIVILIAN WORLD OF COMMUNICATIONS

The recent rapid advances in communications are due to the fabrication of cheap, integrated circuits of huge capacity and complexity. These led the way to a branch of communications system design which relies solely on the transmission of digital information, rather than analogue information, and the application of advanced signal processing within communication systems. The result has been improved quality services such as digital Radio & TV, and the newer digital cordless telephones. It has also brought about the development of completely new services such as e-commerce.

The public experience of personal communications technology is normally through the use of cell or mobile phones and the Internet. Yet also consider the vast range of new services planned for the next few years. Bluetooth and similar standards, for example, aim to provide short-range ad-hoc networking of computers to printers, personal digital assistants (PDAs or palm computers), interconnection of intercoms and many other applications where data requirements are modest. When the amount of data is high other standards and wireless local area networks (wireless LAN) will provide interconnection of radios, TVs and HiFi around the house at data rates of 20-30 Megabits per second. No more a tangled knot of cable around the edge of the room!

## 1G, 2G and 3G

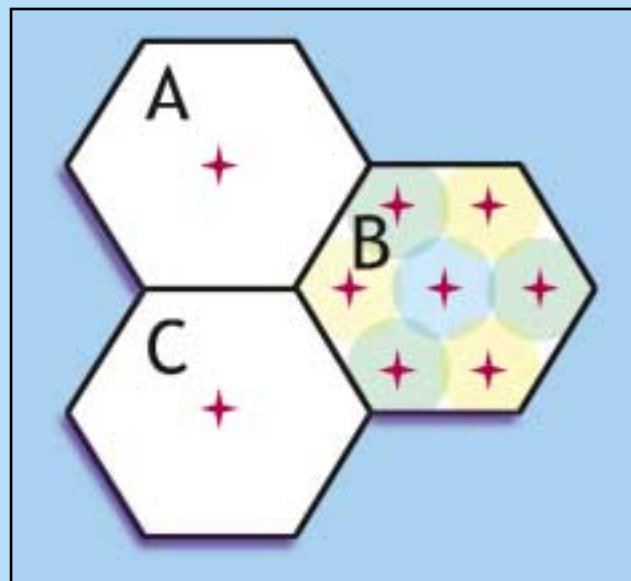
The first operational cellular communication system was deployed in the Norway in 1981 and was followed by similar systems in the US and UK. These first generation systems provided voice transmissions only using frequencies around 900 MHz. These 1G systems used analogue modulation and provide only for voice transmission. Second generation (2G) GSM (Global System for Mobile Communications) was first used in Europe in the early 1990s. GSM provides voice and limited data services and uses digital modulation with improved audio quality. So-called '2.5G' systems recently introduced enhance the data capacity of GSM and mitigate some of its limitations. The new third generation (3G) cellular services known as Universal Mobile Telecommunications System (UMTS) or IMT-2000 will sustain higher data rates still and opens the door to many internet style applications.

The longer-term commercial vision is for high data rate wireless communications between portable terminals that may be located anywhere in the world and which may be located either indoors or outdoors. The minimum target for 4G systems will be 1-20 Mb/s and at least 2 Mb/s to moving vehicles. Fixed wireless access technologies are also being developed to bring high speed Internet access, multi-media and other broadband services to the home. Satellite systems and wireless access to the terrestrial broadband (cable and fibre) networks are possibilities. The combination of new mobile cell phones with global positioning system (GPS) technology also allow the concepts of 'messages in space', which will only be received or picked-up when the user gets near to or in a certain area. Such concepts will be useful for personalised local advertising and information services.



BOWMAN will offer a new communications system, allowing both voice and data links at a variety of service levels. It is currently a bespoke military system. However, the advent of broad band communications systems in the civil sector will change expectations within the military environment. Later mid-life upgrades and add-ons to BOWMAN could well be COTS based.

## The Cellular Concept.



The cellular concept of two-way radio communications reuses the same limited radio frequency spectrum over and over again - this is its strength.

In the example shown the allocated frequency spectrum is divided into three parts with each assigned to a different cell and area A, B and C. A user in any particular cell will communicate with a centrally located base station, each of which is connected to the conventional telephone network and to other mobile networks. Thus one mobile can talk to any other mobile or telephone user by its base station. As the mobile strays from one cell to another the mobile is 'connected' to another base station using a different frequency set.

Outside of the area covered by the three cells shown above, the frequencies, and associated channels, can be used over and over again by repeating the pattern. By repeating the cell pattern the whole country can be covered using the same frequency allocation. There is of course some interference between cells and this is a major design challenge.

Ultimately, there will be more users than channels but the network can be adapted. One approach involves splitting all or some of the cells into smaller cells. Doing this allows the base station, with its allocated channels to serve a smaller area and can thus cope with higher user demand. More base stations are then required and we end up with a hierarchy of large (macro), small (micro) and very small (pico) cells, for example within individual buildings or rooms.

3G Systems achieve cellular re-use by using a technique called CDMA (Code Division Multiple Access) which was originally developed by military communications for its low probability of intercept (LPI) qualities.

A key feature of this concept is that base stations are in fixed locations, of course this is a serious limitation for the military when operating in areas it does not control.

## THE PACE OF CHANGE

Military communication systems have traditionally been procured with long gestation times, for example 20 years is not implausible. The pace of change in civilian systems is, however, much faster. Indeed it is only 20 years since the first cellular system was fielded in the UK (see [The Cellular Concept](#)). Since then we have moved through two radically different system architectures (see 1G, 2G and 3G) and we are about to embark on our third generation system - UMTS (3G)

Not only have the system architectures changed every 5 to 8 years but so has the underlying technology. Whilst this new technology has made new systems possible it has also allowed improvements to the current system operation and the introduction of new services within the lifetime of each. Cell phones have reduced in size, weight and have much reduced battery consumption as a consequence of this new technology.

A challenge for the military will be to introduce similar mechanisms for technology insertion aimed at improving the reliability, weight, operating costs and even adding the provision of new services without the introduction of a new system architecture. The applications of software radios, low power application-specific integrated circuits (ASICs) and other exciting advances will be fundamental to this process [[see COTS as an Enabling Technology](#)].



Communications (voice and data) on and from the battlefield have always been the cornerstone of successful military campaigns. MoD has a wide range of systems needs from maritime, air and land. These can be contrasted with civil applications of cellular phones, GSM (2.5G and 3G), conventional lines, broadband Internet, DAB and future Bluetooth and a wealth of other new systems and standards in development.

## CAN MILITARY COMMUNICATION SYSTEMS BE BASED ON CIVILIAN SYSTEMS?

Military communications are needed for a wide variety of circumstances from peace keeping to war. Many of these circumstances mirror the requirements in the home so there is a strong temptation to believe that consumer driven systems can be used by the military for all operations. This is known as the commercial-off-the-shelf or COTS approach. So, can a COTS policy for procuring military communication systems really work?

As might be deduced the answer is not simple and it certainly depends on a number of doctrinal assumptions. If all jamming, intercept and EW threats can in general be removed then COTS is certainly an option [[see Potential Problems with COTS](#)].

In reality however, removing the EW threat is unlikely to be achieved and as such it will always be necessary to use a military designed communications system during the critical phases of military operations, when lives could be put at risk by the loss of information and message security. When the military situation has stabilised or when the EW threat is low, for example in the early phases of missions or for peace keeping, then MoD should take advantage of the benefits of COTS systems. As an illustration, the Army might deploy cellular communication systems with a base station network and could provide each serviceman with access to a relatively standard cell phone. At present the use of commercial systems with no military fall back would be unwise mainly because technology which can counter all EW threats does not exist at the moment.

### Potential Problems with COTS

- Civilian communication systems have been designed with interoperability between systems in other countries as a prerequisite and this would provide a simple route to coalition compatibility but it would also allow for very easy intercept and potential eves dropping.
- Civilian cellular networks are very fragile to physical attack of the base stations and the support infrastructure; conventional military communications systems avoid the use of base stations to minimise physical attack.
- Electronic Warfare (jamming and intercept) makes it relatively easy to render most, if not all-commercial radio systems inoperative.

Bespoke enhancements to civilian systems are another possibility, however the increasing level of system integration makes this approach more difficult as time progresses. The economics of the use of COTS systems or COTS technologies need to be constantly reviewed.

## Military Led Communication Systems Development

There are of course many communications regimes where there is no applicable civilian system from which to draw. Examples of this are underwater very low frequency (VLF) communications and high frequency (HF) communications. Although Digital Radio Mondial (DRM) is developing a waveform for civilian digital HF it is unfortunately inappropriate to military tactical HF applications where signal levels are low and where the receiver is often on the move. VLF and HF are good examples of areas where MOD has stimulated and led the commercial field.

For air-to-air and air-to-ground data links huge data rates are often required and there are peculiar problems associated with tracking the signal Doppler shifts introduced by the fast moving platforms. Again, for the foreseeable future bespoke systems are also currently required, as there is no obvious commercial driver.

## THE LAWS OF PHYSICS AND NEW ENABLING TECHNOLOGIES

The direct application of commercial wireless communications systems for operational use by the military is problematical. Perhaps more important for the design of new military communication systems is the transfer of technology, algorithms and know how from the commercial sector and vice-versa, for example the Internet, ARPANet and the underlying technology and concepts for 3G.

A defining feature of both the commercial and military information technology industries is an unrelenting increase in requirement for data throughput. In a fixed wired system the capacity can be increased by virtue of adding new physical resources e.g. new optical fibre etc. In contrast wireless communications require sharing of a finite natural resource: the radio frequency spectrum. The wireless channel, defining the characteristics of the medium over which the information is passed, presents a fundamental technical challenge to reliable communications, constrained by propagation conditions and the Shannon's equation.

## The Laws of Physics Affecting Communications

### Propagation

The propagation of radio signals constrains the range and performance of any radio system. Radio propagation and its interaction with the environment is more problematical for military systems than civilian systems and consequently, although much can be learnt from civilian studies this is a critical niche research and development area.

Absorption (signal loss), refraction and diffraction (signal bending) are just some of the important propagation effects that can occur for a variety of reasons. At different frequencies radio signals may be

affected by passing round or through obstacles. The terrain contours are particularly problematical for both military and civilian Personal Communication Systems (PCS). Radio signals may also be absorbed as they pass through clouds or rain or, they may be bent by the earth's atmosphere (also known as ducting) consequently covering unexpected distances or creating holes in coverage. For these signals we are interested in how the radio waves interact with weather phenomena. Other radio signals may be slowed down and bent by electrons in the ionosphere at altitudes above 100 km and for these we need to study Space Weather, which describes variations of electrons and other charged particles in the earth's near space environment.

Radio propagation studies for commercial Personal Communication Systems have, in recent years, concentrated on supporting cellular systems but exciting new work is now being undertaken to support in-building deployment. Such work is important for covert and other military operations. New and challenging research is also likely to be needed on assimilation of real-time environmental data into the military propagation models. Such work draws on weather forecasting research using 3-D variational techniques. Work in the USA is providing new capabilities for ensuring receipt of communications traffic and equally for ensuring signal denial.

### Channel Capacity

Probably the most famous and important equation in communications system design and research is that due to Claude Shannon and which was published in 1948. This important equation describes fundamental limits on any wireless communications system.

$$\text{Capacity} = \text{Bandwidth} \times \text{Log}_2 \{1 + \text{Signal to Noise Ratio}\}$$

The so-called Shannon-Hartley equation states that the capacity for error-free communications is limited and is both proportional to the bandwidth that the signal occupies and to the ratio of the received signal power to the received noise power. The signal-to-noise ratio term simply expresses the need to reduce natural and random noise relative to the man made communications signal. This can be done by increasing the transmitter power or by improving the antenna system.

The bandwidth used for signal transmission varies from system to system. For example in the 2nd generation cellular system used in the UK the bandwidth is 200 kHz; it is typically 60 MHz in the UK SHF military SKYNET channels.

If the required information transfer is less than the capacity as defined by the Shannon-Hartley equation, then error free communication is possible. If information transfer at a rate greater than this limit is attempted errors in transmission will always occur no matter how well the equipment is designed. The Shannon-Hartley equation is a very good first step in evaluating the feasibility of any digital communications system design. It provides an upper bound, only achievable with infinite signal processing resources.

An important theme of wireless communications research is the development of strategies to reach the Shannon limit and to overcome these issues. Such strategies include the development of new modulation and coding schemes - often described together as the signalling waveform. For commercial designs this can be undertaken without reference to EW considerations, but this is not true for military wireless communications.

### Information Theory and Error Coding

All radio communications systems users want the impossible: worldwide, error free communications. The military user also needs to be able to achieve this without suffering any degradation in performance from EW attacks (jamming and intercept). Shannon's Theorem gives us some insights into why this is difficult or impossible to achieve but propagation and information theory specialists are striving to push the physical laws to the limit.

The last ten years has witnessed a revolution in error control coding led by the invention of 'Turbo' coding in 1993. Turbo codes achieve a performance very close to the Shannon limit but at the expense of considerable processing complexity and decoding delays. With modern very large scale integration (VLSI) techniques this complexity is tractable. Recently there has also been considerable interest in adaptive coding strategies that vary the coding complexity as a function of the signal strength and also in special aperiodic codes (chaotic in nature) for highly secure links.

There is a fundamental trade-off between the bandwidth needed for transmitting signals and information and the amount of information and signal processing required (which also needs battery power) for coding and compression. Most military communication systems need to use both efficiently.

### COTS as an Enabling Technology

ASICs: Application Specific Integrated Circuits and FPGAs: Field Programmable Gate Arrays. The semiconductor industry has evolved from integrated circuits (ICs) developed in the late 1960s which had 10s of logic gates amounting to a few hundred transistors through medium scale integration (MSI) to very large scale integration (VLSI) with millions of transistors.

Application Specific Integrated Circuits (ASIC's) are dedicated micro-circuits tailored for a unique application or function. Eventually one chip or micro-circuit might be a complete 2-way radio - and would provide greatly improved reliability, reduced size and lower battery consumption. Field Programmable Gate Arrays are micro-circuits or chips with large numbers of undefined switches, (logic elements) that can be programmed when desired. The functionality is less than an ASIC but the circuit can be programmed during its life or operation to cope with changing standards or functions and upgrades. Both technologies are important for the military radio designer since they provide the

technology to quickly develop and bring to service new radios such as 'Software Radios', see below. Commercial designs and experience should provide an important technology insertion route into military communications systems.

### Software Radios

Software radios describe an exciting approach using both ASIC and FPGAs and other new technology to allow a re-configurable radio, which can be adapted at the point of use and for different applications.

Conventional radio technology uses a number of analogue hardware components to process the signal. The design is specific to the application as well as having a number of technical disadvantages. Software radio technology is a way of realising a multi-band, multipurpose radio. In the ideal software radio the radio frequency (RF) signals are digitised directly at the antenna and all other radio functions are performed in the digital domain by software on the host platform which might be a flexible digital signal processing (DSP) chip, a computer or even a mobile telephone.

In reality, rather than solely processing the signals in software, a combination of hardware logic circuits, for example ASICs and FPGAs, may be used in combination with the DSP. This approach reduces power, size and cost but at the expense of flexibility. This is sometimes referred to as a digital programmable radio.

Future military radios are likely to be based on the software radio principle since the approach offers flexibility for implementing multi-mode and multi-band radios. In principle the specification could be changed on the fly or implemented quickly and cheaply by utilising a library of standard operating routines. The commercial technology push is currently in respect to 3G systems but huge investments are still required to implement this vision.

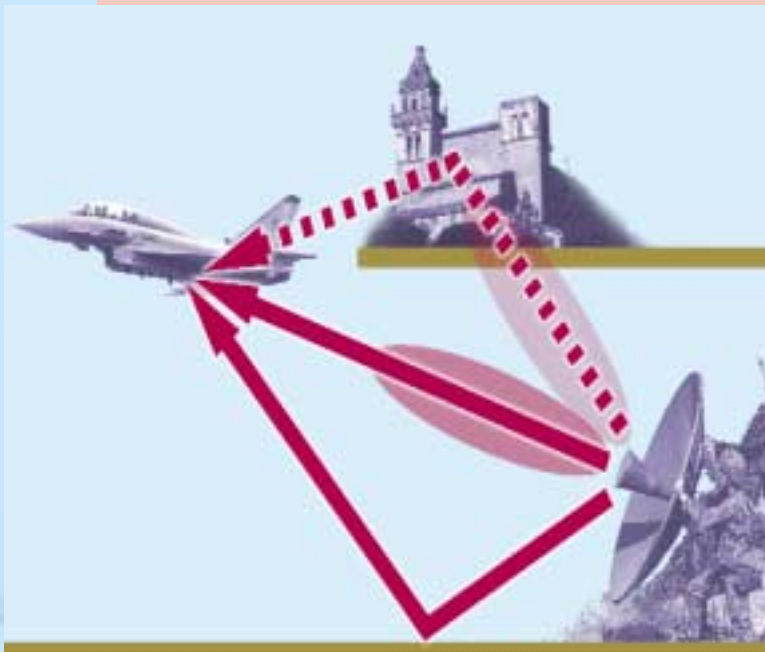
The DSP requirements for 3G commercial systems will require 1 to 2 thousand million-instructions-per-second (MIPS) and this is stretching the industry thus providing new opportunities for technology pull-through by the military. Chip technology is improving through improvements in the chip architecture and in the semiconductor process technology. Clock rates and transistor numbers are being increased, whilst power consumption is being decreased.

Such radio systems have great implications for military users, who are required to adapt to legacy systems and standards and to insert new technology as it emerges from the civil sector.

### Smart Antennas

Smart antennas involve electronic control of the critical elements and provide intelligent functions such as suppression of interference signals auto-tracking of desired signals, and can increase network capacity. They have enormous potential for military operations. Conventional antenna arrays use mechanically steered beams to direct energy to the desired recipient and reduce interference effects. For the future exciting

possibilities relate to the use of "Space-Time Adaptive" processing where multi-path [see picture] is used to advantage to establish a number of parallel and simultaneous channels in the same frequency band.



Smart Antennas are the subject of research at the moment; work is required to ascertain the vulnerability and applicability of these techniques to military systems. However, Smart Antennas have to be achieved at low cost; adaptive antenna arrays are notoriously expensive and any such array has to be immune to jamming. The latter issue, at a minimum, distinguishes the military research from related civilian research into Smart Antennas.

### Infra-Structure Free Networking

The last 25 years have seen an explosive growth in fixed wired networking via cables and optical fibres where connectivity is assured and where the link quality is good and reliable. Wireless networks, particularly mobile wireless networks, do not benefit from these attributes and so cause problems for the Internet transport protocol (TCP).

Research is currently investigating better strategies to maintain the network quality of service in a mobile environment. In particular the use of ad-hoc or infrastructure free networks is currently receiving attention. For example current civil cellular systems consist of a radio link between the mobile handset and a base station but which also need a network infrastructure and control signals. The network connects one subscriber to another, the latter being perhaps part of another mobile or conventional telephone network. In contrast in the ad-hoc network concept, the message from one mobile handset will be passed on by another, to another and onward to the recipient without entering the telephone company's network infrastructure. There are of course significant problems, not least overload of the frequency spectrum and available bandwidth (Shannon's Theorem again), but the lack of infrastructure does make it particularly attractive for resilient military applications.

## THE MOD RESPONSE

It is clear MoD must take note of the civil communications sector. Defence spend world-wide is dwarfed by spend on commercial systems and MoD has no influence on the direction of the mainstream technology. MoD's current programme on communications includes a significant technology watch and awareness activity to enable the use of commercial off the shelf (COTS) technology when it is appropriate. There is a fundamental weakness with COTS technology and its resilience to EW threats (for which it wasn't designed); however, on the other hand the bandwidth available on commercial systems will always be greater than bespoke military systems, which trades-off bandwidth for resilience. MoD must make use of such advantages, like bandwidth and system size/weight, where it can. For example a military radio brought into a country for diplomatic use could draw attention to its later use; however, a commercial radio or phone would pass unnoticed and be perfectly adequate, given the use of suitable cryptographic appliques.

If Electronic Warfare (including jamming and intercept) is a real threat a bespoke system is essential, although in recent small conflicts EW has not been significant and this can lead to a false sense of security. Unfortunately the waveforms used in commercial systems are the crux of its vulnerability, and these are an integral part and the systems and cannot be easily changed. Issues of confidentiality and secrecy; however, can be addressed by the use of appliques.

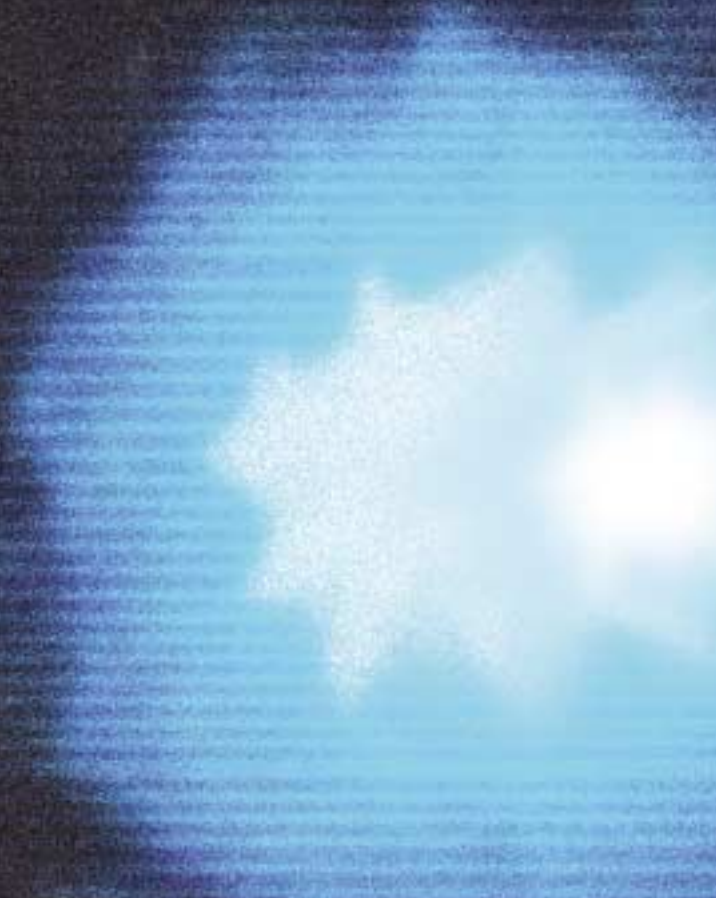
When there is little or no threat of jamming, intercept or other EW, MoD needs to take advantage of the bandwidth and compact systems that COTS provides. Such an approach obviously means that both military and COTS systems need to be carried into operations, and a strategy for their use needs to be developed. Military operations and campaigns occur in different phases and as such the consequent risk levels of an EW threat for a given phase will vary. MoD and the panel agree that at the beginning and ends of a campaign it is useful to make use of the large bandwidth and flexibility which typical COTS systems offer, but in the middle, intense phases, protection against jamming and signal intercept is paramount and bespoke military systems must be used. The policy and plans for using both military and COTS systems must allow for a gentle and graceful transfer from one system to another, without disrupting command and control functions on the battlefield, even though bandwidth and flexibility will change radically. Expectations of system performance (of the COTS/military capability) by commanders and users during the prosecution need to be managed too.

The software radio may be a capability that allows both COTS and military communication systems to be combined. The US is putting significant effort in defining a software radio architecture for all their future communication requirements. Although not strictly commercial, this architecture will become available 'off the shelf' for defence use. The up-front expense of software radio systems means that it is unlikely that such products will find their way into civil systems, but MoD cannot ignore the possibility and needs to maintain a watching brief.

## CONTACTS

If you have any queries on this information on this information sheet or its contents please contact:

Director of Technology Development, MOD,  
Metropole Building,  
Northumberland Avenue,  
London, WC2N 5BP



Satellites are a key part of any communications system required for global force development. Skynet 5 is a service provided by Paradigm Secure Communications for the future MoD system needs. A variety of satellite systems are being offered by a growing number of civil suppliers at reasonable cost, MoD cannot assume opposing forces will not also have this capability.

(Picture of ESAT courtesy of Surrey Satellite Technology Ltd).