Future Communications in a Network-Centric Warfare Paradigm

ABSTRACT

The objective of this paper is to examine the possibilities in the future for communications in the context of global military transformation towards a network-centric and knowledge-savvy force. Network-centric warfare requires an 'entry-fee' which is the cost of proliferating communications equipment force-wide. Given its large numbers, innovative strategies are required to achieve cost-efficiency and effectiveness. A careful study of trends, challenges and technologies is required. A glimpse is provided in this paper to seed an ongoing and necessary discussion on future military communications.

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BACKGROUND

The military transformation process is a long and tedious one. Sweden, for example, has taken the opportunity arising from the end of the cold-war and dismantling of the Warsaw Pact countries to shape its forces for the future through an extended and involved experimentation process that could be a decade long or more. The emphasis is on getting network-centric architectures, concepts of warfighting and methodologies right instead of just on operational readiness. The stakes to transform are very high and countries have to take more than a leap of faith.

Operation Iraqi Freedom (OIF) validated some of the touted benefits of a joint and fully networked force – massing of effects rather than force, higher force exchange ratios through better situation awareness and coordinated engagements, OIF achieved a 70-90 to one exchange ratio, meaning that for every coalition force soldier, there were 70 to 90 Iraqis. As a reference, Israel achieved a 4-to-1 exchange ratio with the Arab States in the Israel-Arab conflicts. In contrast to Operation Desert Storm in 1991, the US (and coalition forces) employed half the number of troops, one-third the number of air sorties, and only 13% of the munitions in OIF. Some factors that contributed to these numbers: application of precision weapons (almost 10 times more) against Iraqi ground troops (compared to Desert Storm), rapidity and intensity of strikes (munitions in OIF were delivered over three weeks versus six weeks for Desert Storm) and the reduced preparation time of the Iraqis (the Iraqis had five months to prepare in Desert Storm compared to just few weeks in OIF). (Conetta, 2003)

A hidden factor underlying these success factors was the far superior communications capability of the US forces compared to that of the Iraqis. They were able to maintain close coordination, disseminate sensor and intelligence information and enable coordinated strikes over an expanded theatre of operations. While the deployment of troops and application of munitions have dropped drastically, the demand for communications has increased dramatically.

In Desert Storm, 542,000 US warfighters were deployed and used 99 Mbps of satellite communications. In contrast, only 350,000 warfighters (almost half compared to Desert Storm) were deployed but they used a total of 3,200 Mbps of satellite communications. This is almost a 60-fold increase in bandwidth utilisation on a "per warfighter" basis. While further analysis would be needed, it would not be an exaggeration to infer that the intensity of future battles would be proportionate in nonlinear terms to the communications bandwidth applied. Communications connectivity and bandwidth would become a critical success factor in future battles.

TRENDS

Lightness and Agility

As militaries transform, the pursuit of lighter and more agile forces intensifies. The Canadian Army plans to upgrade its light artillery pieces on trucks to increase mobility and sell off its larger self-propelled howitzers. The guns' fire control system would also be digitised. It is anticipated that the digitised system would have a greatly reduced setup time i.e. 30 seconds instead of five to seven minutes for the howitzers.

Both the US[1] and Israel (Jane's Defense Weekly, 2004) are also transforming their ground forces to brigade-sized denominations as the basic combat formation. The US pursues its Future Combat Systems (FCS) programme in earnest and early trials of this capability are anticipated by 2007. The French is an exception, having already based the basic combat formation on

[1]The US Tactical Unit of Action (UA) is brigade-based.

a brigade. Even then, it has embarked on its own programme for "air-land" integration (Bulle Operationelle Aeroterrestre) similar in capabilities to the FCS.

A desired outcome is to bring about an increase in force projection and maneuverability. Force multiplication is achieved through coupling the forces with distributed and/or organic sensors and weapons. The greater lightness, agility and flexibility also means that forces could be re-tasked and probably re-configured to meet a broader spectrum of mission needs i.e. from peace-enforcement, counter-terrorism, low-intensity conflicts to hot war.

Increasing Stand-off Distance

Guided munitions such as Joint Direct Attack Munitions (JDAMs) not only provide greater accuracy for engagement of enemy forces, but are also formidable and relatively inexpensive stand-off weapons. Future versions of JDAMs i.e. JDAM-Extended Range would include the DiamondBack range-extension wing kit. Stand-off weapons will continue to improve in both range and sophistication to counter the threat of increasingly sophisticated surface to air missiles (SAMs) that can engage targets 150 to 200 miles away. Besides providing a tactical advantage, increasing the stand-off distance also provides an asymmetric advantage – an ability to strike decisively at an enemy's centre of gravity while still beyond reach and thus avoiding physical harm. This trend applies not only to air-to-surface munitions, but also to other weapon systems being developed.

Ground-to-ground munitions have increased the ground forces' capabilities to engage enemies from beyond line-of-sight (BLOS). For example, a new multiple rocket launcher (MRL) developed by China, WS-2, will have a maximum range of 350km and a circular error probable (CEP) of 500m. Compare this to the WS-1 developed in 1980s, which has a maximum range of 100km and CEP of 1% (of the rockets' range).

Sophisticated stand-off weapons are not only available but affordable. The down-side of such weapons is that they cannot be re-tasked and this makes engagement of mobile targets more difficult. However, this is expected to change. Communications systems can be coupled with weapon systems to aid re-tasking and real-time mission tailoring. Development of future unmanned combat vehicles with a space entry/re-entry capability further ups the ante on increasing stand-off sophistication of weapons. This development trend creates the strategic option for pre-emptive strikes, helping militaries challenge the tyranny of both space and time.

Engaging an Elusive Enemy

The evolution to a future network-centric, knowledge-based force will require the pursuit of pervasive and persistent intelligence, surveillance and reconnaissance (ISR) capabilities to improve the protection and survivability of future lighter and mobile platforms and engage enemies at the earliest opportunity in complex operational terrains e.g. urban environments.

In many aspects, network-centric warfare recognises the importance of "time" as an important element of force multiplication. The military wants do things in shorter times: decisions must be faster, sensor-to-shooter chains must be reduced and forces must be deployed in shorter time. Secondly, the military wants time to be completely non-existent; at least it does not want it in the equation, for example persistent sensors and sensor networks can detect targets with zero time tolerance.

Zero time tolerance is the key to the military's capability to deal with sudden changes and surprises. This concept will drive a pervasive and persistent ISR concept. It is developing on two fronts: a) networking of strategic sensors i.e. imagery satellites, AWACs, etc and b) networking of tactical sensors which includes every soldier and platform (manned/unmanned) as sensor nodes.

A future sensor network is anticipated to be highly heterogeneous, both physically and functionally. Physical nodes can be very big and heavy, like satellites and Boeing 747 type aircraft; they can also be portable (i.e. a network of portable acoustics sensors) (Scanlon et al, 2004) and highly compact devices like micro-sized detectors i.e. motes that can be dispersed in large quantities in the field. Functionally, sensors have to deal with a spectrum of threats: both conventional and non-conventional targets i.e. from SAMs to biological, chemical and nuclear devices such as "dirty bombs".

A pervasive and persistent ISR architecture will need to deal with competing demands arising from the heterogeneous nodes, disparate functions and both temporal and spatial distributions. Yet, a single picture has to exist that yields coherent understanding and decisions.

Unmanned Aviation Integrated with Land Combat

As unmanned aerial vehicles (UAVs) enter mass production and prices fall significantly, they could be deployed in larger numbers economically. A communicating fleet of UAVs could be explored to provide force protection and precision attack capabilities[2].

UAVs are anticipated to be fielded in greater numbers in the future. The competition to build and sell the next-generation UAV and unmanned combat aerial vehicle (UCAV) is fast heating up both in the US and in Europe. UAVs have the potential to actively shape the battlespace by extending sight and weapon reach closer to the enemy farther out. If the UAVs are cheap enough, there would be no need to consider their return, unlike manned missions. Asymmetric strategies such as the Japanese "kamikaze" flights that devastated the Allied navies in the Pacific during World War II could possibly be executed at a comparatively lower cost with higher efficiency.

UAVs have a great potential to impact and transform the land battle by providing tactical responsiveness and extending the sight and reach of military means. Even if it tilts the loss exchange ratio in a land combat slightly by 10%, tens of thousands of soldiers could be saved (based on a deployment of few hundred thousands in a typical land battle). The concepts and the right numbers to achieve the desired effects will have to be experimented and developed[3].

CHALLENGES

The challenges for communications are two-fold: communications as an enabler and communications creating a direct impact on war outcomes.

Communications as Enabler

The trends outlined earlier impact future military communications. With lighter and agile forces, it is possible to have greater dispersion of forces. Improving the speed and span of command is necessary. This is not conceivable without communications systems bridging the distance and the ability to push and pull information on a demand basis. Current communications systems either do not meet the mobility or range requirement or both.

In an integrated "C4ISR-kill" (Command, Control, Computer, Communications, Intelligence, Surveillance and Reconnaissance-kill) future, the communications range must at least be as far as the range of the stand-off distance. This will enable concurrent real-time mid-course guidance and correction, target tracking and estimation of impact, possibly through a video link embedded within the weapon. Providing a dedicated link is feasible.

[2] US Joint Unmanned Combat Air Systems (J-UCAS) is an example.
[3] US Future Combat Systems Programme has developed a 4-tier UAV architecture that relies heavily on UAVs.

However, synergising such links to form a coordinated and integrated network with an element of stealth is a technical challenge.

Pervasive and persistent ISR is only possible if there is pervasive and persistent communications. It is difficult to envision this any other way, except if the military could tolerate delays. This imposes significantly different and stringent requirements on the communications system. As described in the previous section, the ISR network is likely heterogeneous. This makes network co-ordination highly complex. In addition, both range and data throughputs are stretched to their technologically possible maximum. In the future, where more nodes co-exist in a network, an exponential increase in network capacity is required. System availability is also a major concern since persistence becomes the key criterion and this will normally conflict with what is physically achievable.

The integration and harmonisation of unmanned aviation with land combat would be a significant challenge for communications. Issues of electronic warfare vulnerability, information assurance, and overcoming sporadic but frequent intermittent communications loss must be resolved. Different communications architecture is being experimented with but more key R&D challenges are still ahead, and none of the competing technologies seems to be efficient and affordable.

Communications Creating Direct Impact on War Outcomes

Unlike the platform-centric era, the network-centric paradigm suggests that the network itself creates and holds value for the warfighter. To illustrate this point, the US Co-operative Engagement Capability (CEC) system improves the anti-air warfare capability by fusing correlated sensor tracks into a coherent picture that enables precise and rapid engagement of fast moving targets (missiles, etc), These advances were previously impossible with existing sensors operating individually. The new capabilities are not enabled by the existing sensors, which are neither updated nor changed, but by the networking and information processing system.

Because the network is now directly responsible for the effects, it is necessary to study the network just like any weapon system: vital attributes of the network should be examined and linked to desired war outcomes.

For example, by using a proof-of-concept simulation model, combat outcome (effects) was related to decision processes and C4ISR capabilities (Gonzales et al, 2001). The scenario includes two opposing tank divisions with equal capability, except where the "red" force has an almost 2:1 force ratio advantage while the "blue" force has a speed advantage (its tanks have almost twice the speed of "red" tanks). The results relating to communications impact are indicated in Figure 1.

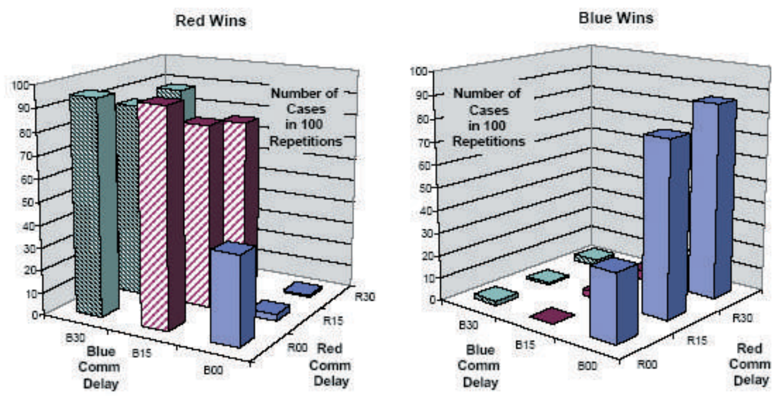

Figure 1. Impact of communications delay on battle outcome (Gonzales et el, 2001)

The numbers on the horizontal axes refer to communications delay in minutes while "B" and "R" give attributes of blue and red forces respectively.

A significant result shown on the left chart is that the red force almost always wins if the blue force has a significant communications delay – 15 minutes or more. Once the blue force's communications delay falls below 15 minutes, any relative advantage that red has over blue is lost (red has a 2:1 force ratio).

The right chart indicates similar results: that blue force is able to achieve a relative advantage over the red force once its communications delay falls below 15 minutes. In fact, as this delay reduces to zero, the blue force is almost always able to exploit its relative advantage (twice the tank speed) to create an absolute advantage and achieve total annihilation of the opposing force even though the red force has a 2:1 force ratio advantage.

Two observations can be made. First, the network determines whether a force is able to convert a relative advantage (i.e. superior platform numbers, superior platform speed etc) into an absolute superiority. Second, the network exhibits force multiplying effects only when the network latency is reduced below 15 minutes. In this scenario, 15 minutes latency is a critical threshold factor – a 'magic' network number or attribute that determines if the network exhibits force multiplying effects.

The threshold factor or 'magic' number/ attribute may vary according the scenarios. Even if the network is expensive and "gold-plated", it may not benefit the battle outcome if it does not satisfy the 'magic' number/ attribute. Is this threshold factor significant? How can it be explained? Threshold effects occur in nonlinear, dynamic systems. Network-centric warfare which relies on "system of systems" are naturally large, nonlinear and dynamic systems. It is therefore not surprising to find threshold effects although they are new and deserve further study and investigation.

Although the above example examines a limited scenario, it provides some insights into the complexity and challenges of architecting, design and implementation of communications networks for the network-centric warfare paradigm. Communications engineers should focus on understanding network attributes contributing to battle outcome. If this is accomplished, it has potential to give greater significance and value to the R&D we pursue and provide a higher performance to cost ratio for communications networks developed or acquired.

TECHNOLOGY

It is almost certain that there are no current communications systems that would meet all the challenges outlined. Furthermore, such solutions have to be cost-effective. While it is not possible to define the solutions now, important technologies will inevitably shape the solutions.

Space-based Communications

Space-based communications can serve a wide range of military communications needs. It operates on line-of-sight principles. However, it can occupy orbits ranging from 400km (Low Earth Orbit) above the earth up to 37,000km (Geosynchronous Equatorial Orbit) from the earth. Thus, it has the possibility to provide non-line of sight communications to warfighters in all the domains of land, air and sea. For example, with only three satellites in geosynchronous orbit, it is possible to provide full earth coverage. This means that if achieving communications persistence is key, then space-based systems are the most direct means.

The current generation of satellites such as IPStar, Anik-F2, WildBlue (recently revived), have capacity in the tens of gigabits per second of information. They cost between US$350 million - US$420 million to build, launch and operate with ground facilities. One observation is that these satellites are bigger and heavier than their conventional counterparts.

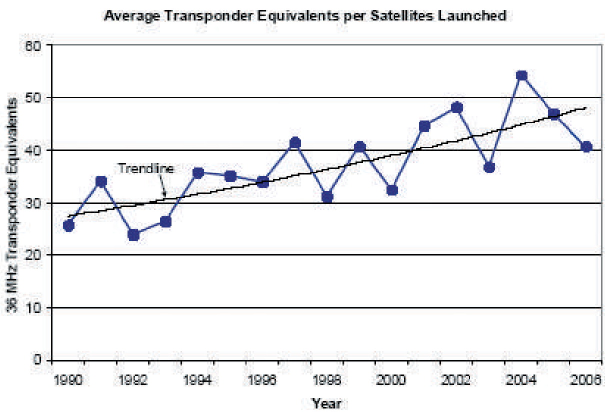

Figure 2. Average transponder equivalents per satellite launched (Futron, 2004)

A study of the chart in Figure 2 indicates that the average transponder per satellite launched has exceeded 60 transponders and an increasing trend has persisted for the past 15 years. This trend is in line with our observation that bigger and heavier satellites will be launched. (Satellites like Anik-F2 have approximately 80 active transponders at least or exceeding 36MHz.)

The chart in Figure 3 indicates that the quantity of satellites launched over the next decade will be almost flat. A maximum of 15 launches per year is expected.

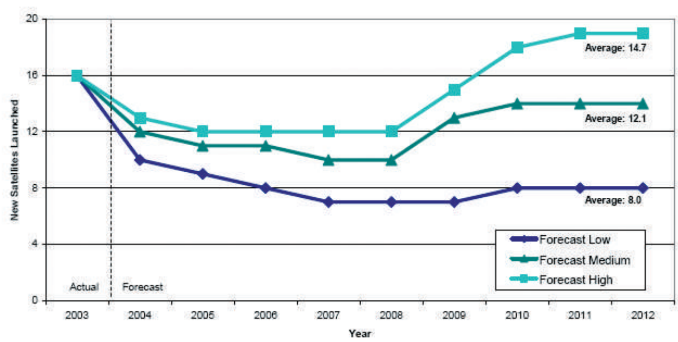

Figure 3. Trend of satellites launched per year (Futron, 2004)

Satellite bandwidth will increase, and the utility of satellite-based communications will probably broaden over the next decade. (This trend shown does not consider the bandwidth of military-launched satellites.) However, the sheer numbers also indicate that the total cost of ownership (TCO) of satellite-based communications systems is probably still going to be high in the near future.

For the military, this is both good and bad news. The good news is that it is possible to leverage satellite systems for broadband, persistent communications covering a wide area. This gives some sense that at least part of the communications problem can be solved to enable future military concepts. On the other hand, the high TCO may mean that the military will have to find the will to commit more resources or find other low-cost alternatives.

An alternative and promising approach is to share the TCO with a commercial service provider. Countries such as Australia, Korea and Spain have done this. Co-shared civilian and military satellites are a feasible possibility.

Yet another approach is not to follow the trend (bigger, heavier satellites) but invest instead on small geosynchronous satellites. In this approach, the number of transponders carried will be reduced. However, the advantage of range and bandwidth is still relatively intact. It may mean however that intelligent bandwidth management may be necessary to de-conflict use. Intersputnik estimated that this approach will reduce the TCO by 350%. Each small geo satellite could cost (including launch and ground control facilities) between US$50 million - US$60 million and carry approximately 10 transponders. Initially the technology will enable C- and Ku-band transponders but will be evolved to Ka-band transponders, optimising the payload to bandwidth ratio. (If 10 Ku-band transponders were carried, this could translate to an information rate of between 540 Mbit/sec to 1 Gbit/sec)

Along this trend of small, agile and flexible satellites, a swarm of multiple low-weight satellites could also have the potential of reducing platform and launch costs. The European Space Agency (ESA) received 70 proposals in its recent call for proposal (RFP) for Earth observation missions (SpaceNews, 2004). Of these, 16 proposals had concepts that either required formation-flying satellites, or similar designs.

If the small geo satellite or the formation-flying satellite business model proves to be a feasible one, the military will be able to exploit it for future military applications at a fraction of the cost that are necessary with current big geo (commercial) satellites.

On-Demand Stratospheric Satellites

Stratospheric satellites are another possibility. These are essentially platforms that operate approximately 21km above the Earth's surface. At this height, the stratospheric winds would be relatively weak and power expenditure for stationkeeping will be lower. At this range, these balloons act as enormous virtual antenna towers for radio communications offering excellent look angles for 40km-80km diameter coverage and degraded performance beyond 100km. (The look / elevation angles are absolutely essential. Lower flying platforms can offer good elevation angles for communications but with limited coverage area. Thus, lower flying platforms are more suitable for enabling tactical communications coverage.) For wider coverage, multiple stratospheric satellites are networked together. However, the real advantage is that they are more responsive than satellites in terms of launch on-demand capability and they are expected to cost much less than a heavy geo satellite i.e. not more than US$10 million per platform. This makes it possible for these platforms to serve the needs of tactical forces in addition to strategic requirements.

There are competing technologies in this area. High Altitude UAVs, NASA's Helios and "high pressure" balloons are some examples. NASA's Helios has demonstrated working relay links (cellular payload) at an approximate height of 60kft (although the Helios has achieved near 100kft) with terrestrial terminals. However, it has limited payload capability which in turn limits the capacity and bandwidth of the application. Companies like Sanswire have also advertised tests of platforms that have potentially higher payload weight. It is an attractive technology for the military. It is expected this will accelerate the development in the near term. When it is ready, the military would have another alternative technology to enable its network-centric concepts.

Software Radios

The value of both satellite and aerial systems (i.e. stratospheric satellites) is that they enable the question of range, persistence, bandwidth and capacity to be taken out of the equation simultaneously. However, to exploit the advantages of such systems, we would need terminals that can operate at the appropriate power, bandwidth, form, fit and function. These terminals must be fairly resistant to intentional and non-intentional interference, be portable and mobile, and cost-efficient. In some scenarios, these terminals should operate autonomously and exploit peer-to-peer communications opportunities without the presence of advantageous relays i.e. satellites, etc. Therefore, these terminals should operate with and without advantageous relays.

If such terminals are a technological goal, they would be very complex and also very expensive as a result. In order to increase the performance to cost ratio, it is necessary to consider a different paradigm.

Software radios provide a new paradigm. There are three aspects to this paradigm: business model, technical and cost. First, the business model. Software radios have a distinct vision – redefine the radio supply chain and adopt a disintermediation process as its key driver. Through disintermediation, the component supply base will be broadened, competition results, and greater market transparency is achieved – individual suppliers' technical competitive advantages and prices are clear. The military will not be held hostage to a few key suppliers ("lock-in" effect) and could instead exercise selectivity and choice in its acquisition and upgrade plans for radios simply because multiple sources are now possible even for a single component. The supply chain is also more efficient because every component is subject to competitive forces – only suppliers with distinct competitive advantage will be selected. Where the market does not exhibit significant differentiation in quality or technical superiority for certain components, these would be acquired or upgraded possibly at lowest quote.

In order to achieve this vision, a de facto architecture standard is required. The de facto standard currently is the US Joint Tactical Radio System – programme's Software Communications Architecture (SCA). The existence of a de facto standard encourages different players to enter the market and compete. These players include both military as well as commercial off-the-shelf (COTS) equipment manufacturers. This helps not only to bring in commercial best practices, but also share economies of scale through leveraging commercial large-scale manufacturing processes and components.

Technically, the software radio is different from previous military tactical radios. It is designed with significantly different requirements. Current software radios operate across 2 MHz to 2 GHz and can support instantaneous data rates up to 100 Mbps or more. Compare this with a conventional tactical radio (see Figure 4 for a table of comparison) and it is obvious the two are designed with very different considerations in mind.

	Software Radio	Conventional VHF Tactical Radio	WiFi (COTS) 100 MHz
Spectrum Access	2 GHz	50 MHz (30 – 80 MHz)	(ISM Band)
Data Rate	10-100 Mbps	64 kbps	10-100 Mbps
Range (LOS)	30km	30km	~100m
Anti-jam / LPI / LPD	Yes	Partial Yes	No

Figure 4. Comparison of software radios and conventional radios

The software radio is designed with access to as wide a spectrum and as high a data throughput as technology can afford to meet the demands of future network-centric warfare. It is also designed for longer range operations and to counter electronic warfare (EW) threat.

In terms of cost, a software radio such as the JTRS costs approximately US$120,000-US$150,000 per set, for a four-channel system. This means that per channel cost is US$30,000-US$38,000. However, this is for the new prototypes (low rate initial production). It is anticipated that the disintermediation process for software radios will drive costs down. Furthermore, a growing number of military/commercial partnerships have been able to produce lower-cost systems. Table 1 gives some examples of US Department of Defense systems that have benefited from military/commercial partnership related to communications (Board on Manufacturing and Engineering Design, 2002).

By adopting commercial best practices for military equipment manufacturing, the cost

Table 1. Successful Cases of Military and Commercial Partnerships (Board on Manufacturing and Engineering Design, 2002)

Performer--Project	Actions (Summary)	Results
Rockwell Collins – Navy ARC-210 radio	Redesign for commercial parts and processes; annual design reviews; maintenance and availability responsibility with contractor	Price reduced 42%; field reliability (MTBF) increased from 500 flight hours to 807 (+62%); annual cost reduction and reliability improvement; eliminated parts obsolescence
USAF ESC/Rockwell-Collins – JTIDS receiver/synthesiser PWA (uninhabited fighter environment)	Evaluated military certified parts, commercial parts meeting military temperature requirements, and commercial parts using both military and commercial assembly	Military assembly costs 15% higher; using mil-temp passive and 10 commercial (of 33) active components reduced material cost by 23%; quality as good as or better than for commercial component failure rate lower than military; process-related failures equal, even with more inspection in military process
USAF ESC/GEC-Marcon – PLSR RF module	Commercial parts and processes substituted for military	65% reduction in material cost, 30% reduction in labour for assembly, test; same electrical performance

was reduced by 50% or more. Also, based on US SINCGARS (Single Channel Ground-Air Radio System) radio cost trends, which shows a reduction of price from US$16,000 for an initial prototype to US$3,000-US$4,000 for the current version over a period of 10 years, we can anticipate that future software radios could cost substantially less to own. Based on these trends, an optimistic projection of the cost of software radios in a decade's time would range from US$8,000-US$10,000. This would still cost more than twice that of a conventional tactical radio but would provide capabilities that exceed current data rates by at least 20 times and bandwidth access by 40 times.

Waveforms

Waveforms developed to SCA-compliance control the functions of a software radio. In monolithic conventional tactical radios, the waveform and the radio platform are integrated and indivisible. For the software radio paradigm, the radio hardware and the software that controls the radio and how radios network are independent. This means also that approximately 70%-80% of radio and radio network intelligence will reside in software waveforms instead of the radio hardware platform. The software provides a competitive advantage by enabling customised waveforms (ECCM (Electromagnetic Counter Counter Measures), LPI/LPD (Low Probability of Interception/Detection), cryptographic algorithms, specific network protocols i.e. MANETS (Mobile Ad Hoc Networks) to operate and run on third-party hardware radio platforms.

It is likely that hardware radio platforms will be increasingly commoditised. However, the software radio will create the "secret edge" in radio communications and networking, and the development costs of such software are likely to remain high. However, if a waveform repository is established, the re-use factor of such waveforms is high. Not only will it foster greater interoperability but will evidently reduce development costs over time.

In an analysis of costs on existing and future-oriented US Navy network-centric systems, some lessons are given:

> "The costs and challenges of the CEC and Intranet (FORCEnet) programmes can be summarised according to their network interaction categories. The Category 2 Intranet programme has experienced delays in implementation and high recurring costs because it has hundreds of thousands of users (high reach) and high numbers of legacy systems and applications and need to access stored data (high intensity, capacity, and richness). The Category 4 CEC programme is networking hundreds of platforms rather than hundreds of thousands, but its high requirements for timeliness, monitoring, and robustness have driven high costs for development and for procuring each individual unit in the network."
>
> (Perry et al, 2004)

Therein lies the beauty of developing common SCA waveforms and establishing an SCA waveform depository: 75%-80% of a waveform developed could be used across wide categories of networks; while 20%-25% of waveform features need be customised for specific scenarios and requirements.

CHANGING THE PARADIGM

We have reflected on some NCW trends and technologies that would mature in the future – some would be wildly successful ("killer apps") while the rest would be discarded with lessons learnt. In the context of communications and IT in general, how should we fashion our own communications systems for NCW? Some thoughts on this:

- "Think Super-Small"– A pico base-station today for cellular communications has approximately the same dimensions of a desktop PC. A mid-size satellite weighs approximately 2-3 tonnes. As a result, the mobility of such equipment depends on the capability of the transport. The availability and nimbleness of the transport limits the mobility patterns of communications and hence, future warfighters. R&D on transport aircraft and new space systems launchers are geared towards higher weight payloads. The use of such transports drives up the cost of the infrastructure and logistics exponentially, while the technology behind it progresses linearly. It seems an expensive proposition to think "big". Communications should think "micro" and "pico" where there is a potential non-linear leap in capabilities to be obtained.

- "Think asymmetric advantage" – In the past, the bulk of communications R&D funds comes mainly from military sources. In the last 10-15 years, that trend has changed. Now, the commercial sector spends more on communications R&D (i.e. 3 / 4G (Third/Fourth Generation Cellular Communications), Wireless Lans (WLANs), Ultra Wideband (UWB) etc) than the military. Consequently, commercial communications systems have been increasingly more capable (extremely high data rates), flexible (size and interoperability) and affordable (i.e. 802.11a/b/g wireless LANs). These factors combine to make commercial systems based on commercial standards extremely attractive to the military. However, these systems, chipsets and knowledge of the intrinsic design are free access to all. This makes it difficult to differentiate networks based on commercial standards and systems. Furthermore, their "signatures" are known and their weaknesses can be targeted for exploitation. In a network-centric paradigm, where the network makes the difference in battle outcomes, network differentiation and information "stealth" is critical. This is where commercial systems and standards fall short. I would advocate customised "smarts" (software) in affordable hardware (e.g. leverage commercial parts, etc). Within this context, core capability to develop waveforms is critical.

- "Building Capacity On-Demand, Rapidly" – If the key to future warfare is agility, precision, persistence and speed, then the ability to focus communications capacity on-demand rapidly would be significant. This indicates that systems such as stratospheric satellites (or similar systems), where on-demand launch is feasible, would enable capacity to be built up rapidly and directed at specific "hot-spots". Furthermore, stratospheric satellites which can be projected and deployed in short timelines would be a valuable asset. Thinking "Super small" complements this by relaxing the requirements (i.e. weight, size, etc) on projection and dispersal means and enables more efficient and effective means of scaling up the numbers.

- "Measuring C3-ISR Systems Like A 'Weapon'" – The fundamental philosophy of NCW is that the network makes the difference. Based on this fundamental philosophy, the concept of networks as enablers do not reap the full benefits of NCW. Instead, they should be measured just like "weapons" that create its effects. Moreover, this measure of effects could potentially help us innovate and re-balance the "kill-chain" for higher cost-effectiveness.

CONCLUSION

As the military transforms into a network-centric, knowledge-savvy force, new requirements will re-define future communications. Innovations will be shaped by new operational concepts and weapon and sensor trends. In the new paradigm, communications will not only be an enabler but will directly impact war outcomes. Achieving a deeper understanding of communications linked to war outcomes will create a new frontier. Essentially, communications engineers will need to be increasingly multi-disciplinary to meet the new challenges.

Old and new technologies converge to shape tomorrow's communications solutions. Each of these new technologies has the potential to drive modern warfare concepts. They also have business models that have potential to drive the total cost of ownership down. These technologies should be explored and experimented and only acquired after sufficient integration and maturation of operational concepts to reap maximum performance to cost ratios.

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BIOGRAPHY

Daniel Chia Kim Boon is currently pursuing a Masters of Engineering in Communications Systems at the Naval Postgraduate School, USA, under the DSTA Postgraduate Scholarship. Prior to this, he was a Programme Manager with the Directorate of Research Development where he was in charge of scanning the technology landscape, identifying new communications frontiers with potential military applications. Since joining DSTA, he has been appointed Member of Expert Panel for the Academic Research Committee 2004, and awarded the PS21 Excel Convention 2002 NOVA Award.