# Technology Forecast 2019 – Military Utility of Future Technologies

A report from seminars at the Swedish Defence University's (SEDU) Military Technology Division


## Summary

Four technology forecast reports from the Fraunhofer Institute and two reports from the Swedish Defence Research Agency (FOI) have been reviewed by staff at the Military Technology Division at the Swedish Defence University (SEDU). The task given by the Defence Materiel Administration (FMV) was to assess the military utility of the given technologies in a timeframe up to the year 2040, from a Swedish Armed Forces (SwAF) perspective. The assessment centred on 5G has the perspective 2030, due to the rapid development of telecommunication standards.

In the review, we assess the **military utility of certain technologies** as possible contributions to the operational capabilities of the SwAF, based on identified and relevant scenarios.

The technologies are grouped into four classes of military utility potential: significant, moderate, negligible or uncertain.

The following technology was assessed to have a potential for **significant** military utility:

- Cognitive Radar

The following technology was assessed to have a potential for **moderate** military utility:

- 5G technologies in military applications

The following technology was assessed to have an **uncertain** potential military utility:

- Multi-Domain UxS

The following technologies were assessed to have **negligible** military utility.

- Blockchains
- Optical Atomic Clocks

The method used in this technology forecast report was to assign each report to one reviewer in the working group. Firstly, each forecast report was summarized. A new methodological step this year was for each reviewer to discuss the assigned technologies with researchers from FOI. This proved to be a valuable enhancement for understanding the technologies' present state and likely future development.

The chosen definition of military utility clearly affects the result of the study. The definition used here, 'the military utility of a certain technology is its contribution to the operational capabilities of the SwAF, within identified relevant scenarios' has been used in our Technology Forecasts since 2013.

Our evaluation of the method used shows that there is a risk that assessments can be biased by the participating experts' presumptions and experience from their own field of research. It should also be stressed that the six technologies' potential military utility was assessed within the specific presented scenarios and their possible contribution to operational capabilities within those specific scenarios, not in general. When additional results have been found in the analysis, this is mentioned.

The greatest value of the method used is its simplicity, cost effectiveness and that it promotes learning within the working group. The composition of the working group and the methodology used are believed to provide a broad and balanced coverage of the technologies being studied. This report should be seen as an executive summary of the research reports and the intention is to help the SwAF Headquarters to evaluate the military utility of emerging technologies within identified relevant scenarios.

Overall, the research reports are considered to be balanced and of high quality in terms of their level of critical analysis regarding technology development. These reports are in line with our task to evaluate the military utility of the emerging technologies.

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# Introduction

## Scope

This report is the result of a review of six reports from the Fraunhofer Institute and the Swedish Defence Research Agency (FOI). The task set by the Swedish Defence Materiel Administration, FMV, was to assess the military utility of the chosen technologies in a timeframe up to 2040. The review and evaluation of the technologies form one chapter each in this report.

## References

The following reports from the Fraunhofer Institute and FOI are reviewed:

| | |
|---|---|
| [1] Optical Atomic Clocks | (Fraunhofer) |
| [2] Cognitive radar | (Fraunhofer) |
| [3] Multi-Domain UxS | (Fraunhofer) |
| [4] Blockchains | (Fraunhofer) |
| [5] 5G technologies in military applications[1] | (FOI) |

## Definitions

In this report, the military utility of a certain technology is defined as the technology's contribution to the operational capabilities of the SwAF, within identified scenarios. A capability implies the ability to perform a certain task in order to produce an effect in a certain situation or environment.

If it is unlikely that Sweden will be able to use this technology by 2040, but possible or likely that potential aggressors will, a discussion of how to defend against it is needed.

## Methodology

The method consists of three steps chosen both for efficiency and in order to take advantage of the professional expertise of the reviewer.

**Step 1:** The reports are assigned to participants in the working group based on their special expertise and interest. Each reviewer is responsible for reviewing one technology. Each reviewer discusses the technology with an assigned researcher at FOI.

The reviewer writes a summary of the report, defines one (or more) tentative military technical system, and puts it in a possible scenario for the Swedish Armed Forces in the timeframe up to 2040. The purpose of the scenario is to illustrate the utility of the technology and to put the technology described into a relevant context.

**Step 2:** Each review is discussed at a seminar. At the seminar, the technology is briefly introduced, and the technical system and the scenario are presented. The reviewer's role is to analyse the military utility of the specific technology in the scenario developed. The other participants' role is to support or criticize the concept.

The analyses in the report's forecasts are guided by the following logic. The quality, capacity and efficiency of a military capability in performing this task provides a certain military utility. The quality and importance of the provided utility must always be valued against the

[1] The report is in Swedish, Swedish title: 5G-tekniker i militära tillämpningar.

strength of an opponent's capability. Figure 1 provides a framework for how to evaluate the analysed technologies' potential military utility. For assessing military suitability, the DOTMLPFI (Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Interoperability) framework is used. The technology assessments in the report are structured in the following sequence:

1. Introduction with a description of the technology's present state and Technology Readiness Level (TRL).
2. The technology's possibilities and constraints.
3. Suggested military use
4. Assumptions for the scenario.
5. Presentation of one or two *scenarios* (based on certain assumptions) where the technology is applied in a *concept system* that would best or most likely be of use for the Swedish Armed Forces in the year 2040.
6. A SWOT analysis regarding the use of the technology in the assigned scenario(s).
7. Assessment of the technology's capability impact.[2]
8. Assessment of footprint
9. Assessment of the need for military R&D
10. Finally, a discussion and conclusion regarding the technology's future development, capability impact and military utility.

Each step in this sequence will have, depending on the assessed technology, different precision and impact in the respective analyses.

**Step 3:** The results of the seminars are documented using a modified version of the Delphi method and successive brainstorming and discussion sessions among the writers of this report. Conclusions are drawn concerning the potential for military utility and capability of the technology. This was complemented with discussions with FOI experts on the specific technologies analysed in the six reports.

[2] The impact on one or several of the seven fundamental military capabilities: strike, command and control, protection, mobility, intelligence and information, sustainment and availability.

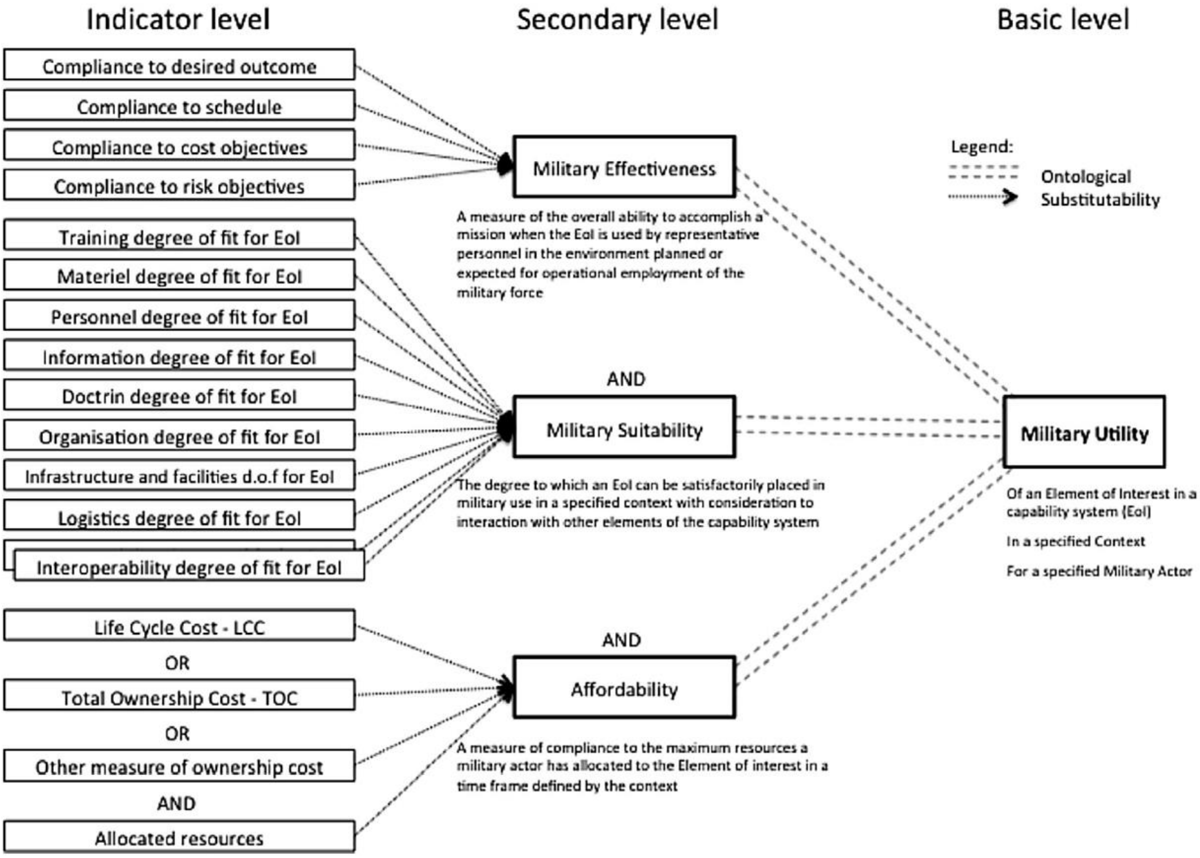


Figure 1. Military Utility consists of Military Effectiveness, Military Suitability and Affordability. Source: K. Andersson et al, Military utility: A proposed concept to support decision-making, Technology in Society 43, 2015. In this framework, the object being assessed is an element in the capability system, labelled the Element of Interest (EoI). LCC is the Life Cycle Cost. TOC is the Total Ownership Cost.

**Composition of the working group**

The working group consisted of experts from the Military Technology Division at SEDU:

Martin Lundmark, PhD, project manager

Gunnar Hult, Chaired Professor of Military Technology

Åke Sivertun, Professor of Military Technology

Bengt Vretblad, Professor of Military Technology

Peter Bull, PhD, associate professor

Eva Lagg, PhD, associate professor

Daniel Amann, Lt Col (Air Force), PhD student

Kent Andersson, Lt Col (Air Force), PhD

Marcus Dansarie, Cn (Navy), MSc, PhD student

Carl von Gerber, Lt Col (Amph)

Michael Reberg, Lt Col (Army)

Ola Thunqvist, Lt Col, (Navy)

# TECHNOLOGY FORECASTS

**Optical Atomic Clocks**
Ref [1] Referee: Marcus Dansarie
Interview: Magnus Danielsson, Net Insight AB

*Reference:*
Offenberg, D. (2018), *Optical Atomic Clocks*, Fraunhofer Institute, Euskirchen, Germany

**Introduction**

The second is one of the SI base units. It is defined as the transition frequency between two energy levels in the caesium-133 atom. This is the quantity measured by caesium atomic clocks. In addition, rubidium atomic clocks and hydrogen masers[3] are also common as atomic clocks (TRL 9). They measure frequencies of quantum phenomena in rubidium and hydrogen, respectively. Common for all conventional atomic clocks is that they measure frequencies in the microwave (GHz) range. This sets the limit of their accuracy. So-called fountain atomic clocks, which are the highest performing microwave range atomic clocks, provide accuracies in the order of $10^{-16}$ while commercial grade caesium atomic clocks provide accuracies in the order of $10^{-13}$.

In contrast, optical atomic clocks measure frequencies in the optical range, i.e. infrared, visible, and ultraviolet light. In theory, higher frequencies enable increased accuracy. However, the higher frequencies also create engineering challenges. Most importantly, it is not possible to measure optical frequencies directly with electronic frequency counters, unlike in the microwave range. This necessitates conversion of frequencies in optical wavelengths to frequencies in the microwave band, with preserved accuracy, before measurement. Thermal background radiation is the primary source of noise in the optical frequency band, which means that cryogenic cooling is required.

The highest published accuracy of an experimental optical atomic clock is $2.5 \cdot 10^{-19}$. The interviewed subject matter expert emphasized that there are other promising technologies for high-accuracy timekeeping than those described in the report. Therefore, the important focus should be the increases in accuracy that will be possible with new types atomic of clocks rather than specific technical implementations.

Comparing atomic clocks and performing time transfer requires some sort of link between the clocks' respective sites. For higher accuracies, there are very strict requirements on e.g. phase noise and stabilization of the optical path length. This can be both an advantage and a disadvantage depending on the application.

According to the report, optical atomic clocks for basic physics research are presently at TRL 9. Applications of optical atomic clocks are currently not above TRL 4.

An important aspect of increased accuracy in atomic clocks is the ability to resolve relativistic effects. For example, the change in gravitational potential corresponding to an altitude change of one meter causes a time inaccuracy in the order of $10^{-16}$.

**Identified possibilities and constraints**

[3] Maser is an abbreviation, which stands for microwave amplification by stimulated emission of radiation. It is the microwave equivalent of a laser.

The following possibilities and constraints were identified in the report.

*Possibilities*

- Increases in the accuracy of frequency and time of fieldable atomic clocks will enable corresponding increases in accuracy of systems using high frequencies. This will open up new possibilities and can possibly increase performance in sensor systems, especially radars, communication systems, navigation systems, and in the electronic warfare field.

*Constraints*

- Very high accuracy atomic clocks require compensation for time dilatation[4] if they are used in moving platforms. This means that the position and velocity of the platform must be known with very high accuracy.
- Use of very high accuracy atomic clocks for increased accuracy in satellite navigation systems necessitates accurate compensation for atmospheric disturbances to radio signals, which is the current largest source of inaccuracy.
- Synchronizing high accuracy atomic clocks requires optical transmission.

**Suggested military use**

Any application that requires highly accurate time or frequency, such as multistatic high-frequency sensor systems (radar) and in electronic warfare. Multistatic sensor systems have multiple transmitters and receivers that are spatially separated. This enables the sensor system to use several propagation paths to and from each target which increases the probability of detection while reducing the effect of any passive or active countermeasures. An obstacle with multistatic sensor systems is time and frequency synchronization. This is especially the case for high-frequency systems with high signal propagation speeds, such as radar. For example, in a multistatic radar with a 10 GHz transmission frequency and a transmitter and receiver clock frequency stability of $10^{-13}$, the phase error would increase by over 1,000 degrees per hour. This effectively makes it impossible for such a system to use coherent methods. An optical atomic clock with accuracy of $10^{-19}$ would reduce the phase error to fractions of degrees per hour, thus permitting the use of coherent methods.

**Assumptions**

The concept scenarios are based on the following assumptions.

- The technologies have reached the necessary technology readiness level to be utilized in mass-produced products.
- The cost of mass-producing the products is not prohibitively high.
- Communication systems do not require the level of accuracy enabled by optical atomic clocks.
- Stealth technology remains an efficient method for prohibiting detection by conventional radar.

**Concept systems and scenarios in 2040**

[4] Time dilatation is an effect of the theory of relativity. In short, observers moving at different speeds relative to each other will perceive time differently. This is not a measurement error, but an actual change in the perception of space-time.

Concept system 1 GNSS holdover capability

Systems that use global navigation satellite systems (GNSS) to provide accurate time and frequency have been fitted with high-accuracy atomic clocks that provide holdover capability.

Scenario 1 Meaconing detection

In case of GNSS unavailability, e.g. due to jamming, the systems still are still provided with accurate time and frequency for days or weeks. Tight integration of the atomic clocks with the GNSS systems allows for detection of meaconing, i.e. rebroadcasting of navigation signals with the purpose of causing false time and position solutions.

Concept system 2 Coherent multistatic radar

The high frequency accuracy has made coherent multistatic radars possible.

Scenario 2 Airspace situational awareness

Due to synergy with coherent and multistatic technologies, these radars can detect stealth and low radar cross-section targets at much higher ranges than conventional, monostatic, radars.

**SWOT analysis**

*Scenario 1*

*Strengths*

- GNSS systems are made more resistant to jamming and meaconing.
- The long-term stability of the atomic clock enables systems that require accurate time or frequency to function with full accuracy for long times without GNSS coverage.

*Weaknesses*

- Requires precise optical phase and frequency synchronization, which makes synchronization over larger distances hard.
- Requires compensation for gravitational potential and platform velocity.
- Size and weight might prohibit use in smaller platforms.
- Performance gains may not warrant the increase in system complexity associated with introducing optical atomic clocks.

*Opportunities*

- Development of accurate methods of compensating for atmospheric propagation effects would eliminate the largest source of inaccuracies in GNSS signals, thus opening up for a the further increase in accuracy made possible by more accurate space-based optical atomic clocks.

*Threats*

- If the links used to synchronize clocks are sensitive to jamming or other electronic warfare measures, the accuracy gains could be lost.

*Scenario 2*

*Strengths*

- Coherent multistatic radar capability enables detection of targets with smaller radar cross-sections. It also severely reduces the targets' ability to control the radar cross-section shown to a radar by adjusting their aspect angle towards it.

*Weaknesses*

- Requires precise optical phase and frequency synchronization, which makes synchronization over larger distances hard.
- Requires compensation for gravitational potential and platform velocity.
- Size and weight might prohibit use in smaller platforms.
- Performance gains may not warrant the increase in system complexity associated with introducing optical atomic clocks.

*Opportunities*

- Target characterization using multistatic coherent polarization measurements may be possible.

*Threats*

- If stealth technology becomes obsolete through other technological developments, the advantages of multistatic radar towards stealth targets are negated.
- If the links used to synchronize clocks are sensitive to jamming or other EW measures, the accuracy gains could be lost.

**Assessment of capability impact**

All field deployable time and frequency sources with very high accuracy, including optical atomic clocks, are enablers of other technologies. It is those other technologies, rather than the optical clocks themselves, that will provide capabilities of military interest. The main technology enabled by this is coherent multistatic sensor systems with high phase accuracy. Such systems, when deployed, could make significant contributions to situational awareness. This may include an increased probability of detection of stealth and low radar cross section targets. New methods for classification of radar targets may also be possible.

**Assessment of footprint**

| **Influencing factor** | **Footprint** |
|---|---|
| Doctrine | Limited. |
| Organization | Limited. |
| Training | Limited. |
| Materiel | Equipment in need of high-accuracy time and frequency needs to have compliant interfaces. |
| Leadership | Limited. |
| Personnel | Limited. |
| Facilities | Need for optical clock maintenance facilities. |

| | |
|---|---|
| Interoperability | If systems that require high-accuracy time and frequency need to be interoperable, then clock synchronization must also be interoperable. |

**Assessment of the need for military R&D**

Requires R&D in systems and technologies that are supported by highly accurate time and frequency sources.

**Conclusions on military utility and recommendations**

Optical atomic clocks in their current level of technological maturity are only of interest in physics and meteorology research. According to [1], optical atomic clocks for meteorological purposes will reach TRL 9 by 2030. Field-deployable optical atomic clocks for use as gravimeters are expected to be available for use (TRL 7) around 2040. The same TRL and time frame is projected for space-qualified optical clocks for GNSS use. It is thus expected that other uses of optical atomic clocks, such as frequency references for sensor systems, lie even further in the future.

Coherent multistatic sensor systems would undoubtedly provide new capabilities as well as improved performance compared to today's systems. However, the military utility of this is hard to predict. This is primarily due to the uncertainty that exists regarding future prevalence of stealth and other low-observability technologies. With the current development of automation, autonomous vehicles, vehicle swarms, electronic warfare systems, hypersonic weapons et cetera, low-observability may become less important, thus negating the gains provided by more efficient sensor systems.

Based on the projected technological readiness of the technology in the time frame of the military utility assessment and the uncertainties regarding time synchronization and compensation for platform movement, optical atomic clocks have been assessed having negligible military utility.

A higher technology readiness level within the utility assessment time frame would have a positive impact on the military utility. This, together with the potential synergy effects of optical atomic clocks combined with cognitive radar technology, could motivate a new assessment of optical atomic clocks in a decade's time.

**Cognitive radar**

Ref: [2] Referee: Kent Andersson

Interviews: Dr Anders Nelander, researcher, FOI, and LtCol Michael Reberg, SEDU.

*References*:

Karsten, M. (2018), *Cognitive Radar: Artificial Intelligence in Radar Systems*, Fraunhofer Institute, Euskirchen, Germany

Johansson, B., Nilsson, J., Waern, Å, Wadströmer N., Asp, B. & Axell, E. (2015), *Kognitiva System: Teknisk prognos 2015* [Cognitive systems: Technology Forecast 2015], FOI-R—4107—SE, FOI

## Introduction

The general idea is to combine the development in adaptive radar technology with the development in artificial intelligence (AI) to obtain a cognitive radar (CR) sensor. That is, a sensor with many, and wide, degrees of freedom and with (near) human cognitive abilities to react to and learn from environmental stimuli – but with superhuman speed and endurance.

Adaptive radar has been a dynamic area of research since the nineteen-sixties. Multiple-In-Multiple-Out (MIMO) antennas, technology for suppression of side lobes, and Spectrum Occupancy Sensing (SOS) can be considered innovations originating from this area. The reviewed report highlights SOS in combination with future progress in material physics to obtain higher spectral purity in transmitting radars as a current interesting area of progress. With gallium nitride components there will for example be “high frequency amplifiers with excellent linearity, high dynamic and small size”. Combined with SOS this technology has the potential to meet the challenges from increasing competition on the use of available frequencies. In the military context the same technologies will of course be useful to counter electronic warfare. However, there are many other areas where there is progress and the report categorizes the areas in radar resources such as: antennas, usable frequencies, power of transmission, signal and data processing, computational power, or bandwidth for internal and external data transmission. Consequently, complexity increases and the report concludes there are thousands of system parameters to adjust in order to optimise such a radar system. The report also refers to a concept called multifunctional radar. The seminar concludes this concept overlap but is not necessarily equivalent. Figure 1 illustrates some of the tasks possible to solve using a multifunctional radar. The report predicts the adaptive radar technologies will have reached TRL 8-9 well before 2040.

There seems to be no common understanding of the term cognitive radar. But the idea is that the cognition based on AI is to be used to control the radar resources exemplified above. The radars have become so complex and they possess such potential that the report concludes there is a “high demand to develop control methods… that on one hand relieve the operator…and on the other hand to use the radar system to full capacity”. Key is the automation of the decision making for how to best achieve the mission goals set by the operator/organization. Priorities of different modes, searching, tracking etc., have to be re-evaluated continuously due to changing priorities or changing environmental conditions, e.g.

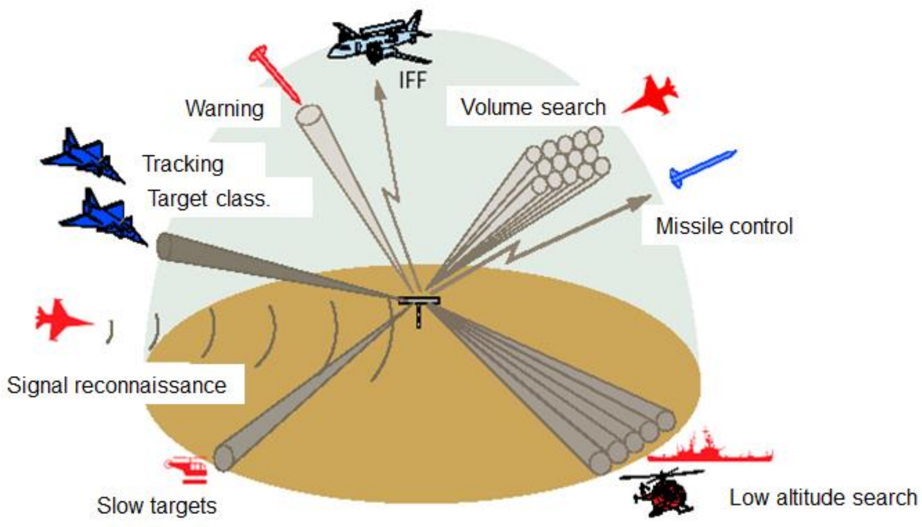


Figure 1. Tasks possible to solve using a truly adaptive/multi-functional radar. The picture is originally from an FOI report of unknown identity (Lärobok i militärteknik, Vol. 2 Sensorteknik, Försvarshögskolan2007, p. 46)

clutter from weather, surface structure, sea conditions etc., in order to continuously find the optimal operational state. The author of the report indicates that this re-evaluation has to occur as often as once every 10 ms. The CR expert interviewed says the physical limit to the re-evaluation cycle is the time-of-flight for the transmitted signal to be reflected off the target and received once again in the sensor. Then of course the signal processing and necessary computations will add time to the perception cycle. The self-learning part of the cognition function recognize misjudgements, adjust parameter settings and learn the lessons. The report predicts that the AI-supported command and control function aspired will have been demonstrated by 2040 but some sub systems will still be under development. In sum, the technology will have reached TRL 7.

**Identified possibilities and constraints**

The following possibilities were identified in the report:

- Permanently applied optimal use of radar resources, thus in a setting were you have CR but the adversary has not, you will have the “reconnaissance superiority”.
- Rapid response to changes in the environment - down to fractions of a second.
- Operators are relieved from workload.
- Efficient sharing of resources in a platform between communications, C2 or sensing. Requires cognitive power on a system level.
- Cognitive Radar Information Networks (CRIN), for building a multistatic radar or to enhance resolution and detection range temporarily using a network of sensors.

The following constraints were mentioned in the report:

- Machine learning is a method for automated learning, but it needs sets of sample data for training. Using this approach a CR will not recognize new phenomena. The FOI report on cognitive systems in general [Ref 2, p28] mentions there are other techniques: like deep learning, boosting, or anomaly detection, and the cognitive control function will probably need a combination of several.
- The necessary time to build the aperture in a SAR is not compatible with the advantages of CR - that is CR will not enhance SAR functionality.

- A CR will have some autonomy as compared to an overall mission of a CRIN and consequently it can behave more or less cooperative within the overall system. How to obtain an optimal behaviour of all group members is a research area on its own.
- CRINs and sharing of resources are constrained by delays in data transmission.
- The verification and validation of learning systems.
- AI and issues of responsibility.

**Suggested military use**

The following military use for cognitive radar is suggested in the reviewed report:

- CR is highly relevant for monitoring battlespace, including in EW contested environment
- The report states that CR supports the reduction of own radar signatures. The seminar´s interpretation is that if your sensor always uses optimum resources relative the missions you will for example not use more power than necessary, and consequently your emitted signature will be reduced. Another interpretation is that the cognitive control function will understand the signature of its own platform if it is aware of the adversary´s sensor positions and status.
- CR achieves more effective antenna management
- CR can provide illumination for other passive sensors or be a passive sensor by its own, including the use in military CRINs
- Combat platforms may use CR for detection and targeting of their own.
- Missile seekers will perform better with CR.
- CR can be used to optimize detection of targets with low radar cross section.

**Assumptions**

The concept scenarios are based on the following assumptions:

- The cognitive control function has been realized to a level useful for optimising radar performance in cycles well within a second. It also possesses anomaly detection and learning abilities in the surveillance context.
- The CRs in the scenarios also include the features usually associated with multi-functional radars.
- The technical performance requirements for the distribution of high quality real time recognized situation pictures in networks, and for supporting distributed computational power, have been solved (not necessary in a one-platform/non-networked concept).

**Concept systems and scenarios in 2040**

*Concept system 1: A system of cooperating cognitive radars*

All radars in the airspace and coastal radar chains, as well as on combat aircraft and naval vessels are designed with multifunctional/adaptive technology and cognitive control functions based on AI. In addition they are designed with communications technology making it possible to network the cognitive radars in order to share resources and distribute computing power. Some of the aircraft have passive radar antennas configured to make it possible to contribute to the multistatic radar chain and to signal reconnaissance. In addition to the cognitive control functions in the respective radars there is a centralized cognitive control function supporting tactical as well as operative command levels. The cognitive radars in the network cooperate to solve tasks/missions on all command levels according to negotiated priorities thereby forming a Cognitive Radar Information Network.

*Scenario 1 CRIN Surveillance*

A year after setting up a new mobile CR in its respective area of operation it has learned the local geography and special weather conditions. The tactical operators have observed the achievement of better detection ranges already as compared to the old reconnaissance radar, especially in bad weather conditions, and especially if the chain is in CRIN-mode. The cognitive radars attend training regularly to learn the latest electronic warfare techniques exercised by regional powers and recorded from signal surveillance. It is becoming more and more challenging to avoid detection using platforms designed with stealth technology and adapted tactics. The centralized cognitive control function makes use of all radar data, even from old legacy radar stations operated by a neighbouring partner country. It evaluates airspace and sea movements over longer periods and makes trend analysis supporting intelligence on both operative and tactical levels.

*Concept system 2 GBAD CR*

The new GBAD CR for the Swedish air defence battalions is designed with multifunctional/adaptive technology and cognitive control functions based on AI. It is networked locally within the battalion but also individually to the Swedish and partners´ CRIN surveillance network. The design has finally realised the long wanted true multi-functionality making it possible to integrate all radar functions needed for GBAD into one technical system. Instead of having to support several different types of technical systems the budget is instead used to finance redundancy.

*Scenario 2 Air defence for Visby harbour and airbase*

The new GBAD CR is now fully operational in the Swedish air defence battalions. During an exercise called Gute hedgehog in the Baltic Sea, in cooperation with German and Finnish forces, the capability of the battalion is demonstrated. Massive cruise missile attacks on Visby airbase and harbour are simulated using German and Finnish UCAVs and are supported with their EW resources. On the first day of the exercise some of the cruise missiles get through and find their targets, but the following day, after the CRs have learned their lesson, the defenders are successful. Due to the new CR functionality introduced there have been changes in the battalion. There are fewer operators in the organisation. But, there is also a new Virtual Battalion Combat Commander (VBCC) function speeding up engagement decisions. The latter function has proven extremely valuable during the coordinated cruise missile attacks. While the human counterpart tires from the long hours of waiting in high readiness and therefore performs poorly when the short but intense attack happens suddenly, the VBCC is always on her toes. The CR supported counter EW abilities has also shown real value. It picked up all through the duration of the exercise and at the end the early warning abilities of the battalion was satisfactory.

**SWOT analysis**

The following strengths, weaknesses, opportunities and threats with the CRIN Surveillance scenario were identified at the seminar:

| Strengths: | Weaknesses: |
|---|---|
| • The optimized performance of each CR results in longer detection ranges and enhanced detection probabilities<br>• True multi-functionality might include new functions like signal reconnaissance thereby increasing probability of classification and identification.<br>• Enhanced performance during EW attacks resulting in a more robust recognized situation picture<br>• Cooperating CRs in combination with low latency networks will realize a multistatic radar function increasing probability of detection for small and stealthy targets. | • A cognitive control function based on AI decreases human operator skills and increases dependence on technology<br>• Increase in complexity, especially in combination with increasing mobility of CRs in radar chains<br>• Cooperating CRs in a CRIN will increase the load in the telecommunications network and might in some situations limit capacity for other traffic. |
| **Opportunities:** | **Threats:** |
| • Enhanced robustness<br>• A centralized cognitive function for the tactical and operative command and control could support intelligence and enhance decision-support (the seminar assess this is out of scope for CRs)<br>• A cognitive control function integrated with a legacy radar station might increase its performance and lifetime. | • Potential adversaries exploit the CR-technology<br>• Legacy systems are probably suboptimized to specific missions and a cognitive function might not make a difference<br>• Societal regulations on the use of AI limits realization of some functions |

The following strengths, weaknesses, opportunities and threats with GBAD CR in the *Air defence for Visby harbour and airbase* scenario were identified at the seminar:

| Strengths: | Weaknesses: |
|---|---|
| • The experiences of one of the CRs in the battalion network is quickly taught to all the others<br>• With the cooperating feature in the respective CRs perhaps the VBCC function is not even necessary - the CRs become self-synchronizing within the network. | • Trust is an issue – in principal all automation can be exploited by an adversary – like clutter maps. By slowly increasing background noise using EW a skilled adversary can reduce detection probability.<br>• A CR includes considerable information on what we know of the adversary tactics and technical systems. That might become a security issue. |
| Opportunities:<br>• The Virtual Battalion Combat Commander (VBCC) was assessed an interesting option but out of scope for the CR concept.<br>• The learning feature of the CRs will shorten the battle-wheel of producing threat libraries dramatically | Threats:<br>• Dependence on automation and loss of operator skills<br>• The cognition capability of the CR might be used reciprocally by a cognitive EW capability<br>• In the end this may lead up to a duel between AIs, with humans left outside of the loop |

**Assessment of capability impact**

The primary impact is on surveillance and intelligence capabilities, with enhanced detection ranges under all conditions, including in EW-contested situations. If used in platforms or missiles these weapon systems will increase their effect (lethality). The secondary impact is on enhanced C2 capability due to more robust and responsive sensors or sensor networks.

**Assessment of footprint**

The following list is a compilation of anticipated footprints on capability development if the technology in focus is to be used as described.

| **Influencing factor** | **Footprint** |
|---|---|
| Doctrine | The technology presents new opportunities to exploit the potential of a radars performance, specifically if CRs cooperate in a network. Technical and tactical procedures would have to develop. |
| Organization | Some roles in unit organizations would change from that of operators to that of analysts. A centralized cognitive control function might render changes in the intelligence organization. No completely new types of units can be foreseen. |

| Influencing factor | Footprint |
|---|---|
| Training | There would have to be new training and exercises on how to cooperate with the AI-based control function. The VBCC function will require a new inspector-role. |
| Personnel | The changes in organization might render demand for new personnel categories |
| Materiel | The opportunity to upgrade legacy radar stations should be taken into account when acquiring the new Swedish radar chain. |
| Facilities | Non identified |
| Leadership | Change management |
| Interoperability | Common standards for protocols, information confidentiality and encryption supporting cooperating CRs |

**Assessment of the need for military R&D**

The research report reviewed indicates there is an interest in the civilian market as well as among military actors in driving the technology development. The seminar assesses that there are some areas of research only interesting to the military sector, like information confidentiality and encryption. However, the greatest need for military R&D is probably in studies on the doctrinal and organizational development necessary.

**Conclusions on military utility and recommendations**

Given the assessment of the technology in the reviewed report, the seminar concludes that the application of the CR concept in a one-platform design, like a UCAV or a missile, will likely increase the military effectiveness significantly. The effective distances for engaging a target will increase as the probability of detection and identification will increase, also in contested environments. If a future scenario involves an equally technologically mature adversary investing in the technology is highly motivated. The footprint analysis indicates that the degree of fit in military suitability is acceptable, but the affordability has not been analysed.

However, the two scenarios in this assessment have both been focusing on the potential in cooperating CRs and in having a cognitive control function on central/networked level. The seminar concludes that this potential is probably even greater than when CRs are used in one-platform designs, as was suggested in the reviewed report. The realization of multistatic radar features is one of the potential leaps in capability. Virtual “commanders” is another possibility. But this step in evolution of surveillance and intelligence is considerably bigger and the uncertainty in technological maturity increases.

**Multi-Domain UxS**

Ref: [3] Referee: Peter Bull

*Reference:*
Huppertz, G. (2019), *Multi-Domain UxS – Enhanced Mobility*, Fraunhofer Institute, Euskirchen, Germany

**Introduction**

Unmanned systems are usually bound to one main operating arena such as the air, the ground, on the water surface, or below the water surface. A multidomain unmanned system[5] is able to operate in more than one main operating arena. One example is vehicles that can fly to a certain destination, dive into the water, move submerged under to gather intelligence, and take off from the surface to fly back to base. Whether these vehicles are really multidomain or rather dual domain is a question left to the reader to decide.

One important challenge for these vehicles is the combination of different types of propulsion. In practical terms it needs two propulsion systems, one of which will be unused during operation. In some cases, it can utilize one system that is able to operate in different media, which will be less than optimal in one of the medias it operates in. Examples of this is vehicles that can fly and dive that uses airscrews for propulsion, or amphibious vehicles that use tracks for propulsion both on the ground and in the water.

Unmanned systems for one medium (e.g. UAVs or unmanned underwater vehicles (UUV)) have been operational (TRL 9) for decades. Functioning multidomain vehicles are presently tested on the concept stage (TRL 5-6). However, the compromise in technology solutions and performance required for one vehicle being able to effectively operate in two medias still present considerable challenges. Whether multidomain systems in 2040 will present a more capable solution than a combination of separate unmanned systems working together is uncertain.

**Identified possibilities and constraints**

Possibilities

- Can offer increased mobility
- Can offer increased endurance

Constraints

- Compromises payload with propulsion systems
- Compromises propulsion system to operate in different media
- Compromises shape to operate in different media

**Suggested military use**

The following applications are mentioned in the report

1. Vehicles that can fly and operate under the water surface
2. Vehicles that can operate on the ground and avoid obstacles by flying over them

[5] UxS stands for unmanned system.

3. Vehicles that can fly to a destination and perch or crawl locally to save energy

**Assumptions**

The concept scenarios are based on the following assumptions.

- The technologies have reached the necessary technology readiness level to be utilized in mass-produced products
- The cost of mass producing these products is not prohibitively high

**Concept systems and scenarios in 2040**

1. Cruise missile that can function as a torpedo
2. Amphibious unmanned infantry fighting vehicle

*Scenario 1 – Cruise torpedo*

Modern warships have a wide array of sensors for situational awareness and weapon systems for protection against anti-surface missiles. Their protection against torpedoes on the other hand usually depends on the integrity and mobility of the vessel. Therefore, an anti-surface or cruise missile that can convert into a torpedo when it is close to its target could possibly take advantage of this. The missile is fired from its platform and flies towards its target. When it reaches the range of the targets defensive systems, such as CIWS[6], it can jettison its wings and engine used for propulsion in the air and dive into the water. Under water it moves towards the target at a speed that will make it difficult for the target to escape the torpedo. It is not assumed that the torpedo moves in the water as a super cavitating missile, but rather as a reasonably quick torpedo. Alternatively, it flies towards the target as a regular anti-surface missile.

*Scenario 2 – Unmanned IFV*

Currently manned unmanned teaming, MUM-T is being actively researched both for aircraft and for ground vehicles. An unmanned IFV that could operate in a MUM-T scenario could be used as a forward scout or weapons platform. In order to do that it would have to be capable of traversing difficult terrain. An unmanned vehicle does not have to cater for the needs of a crew. The vehicle could share significant parts, such as chassis and tracks, with an existing manned vehicle. This would still allow for the vehicle to be relatively small and light compared to a manned counterpart. Such a light tracked vehicle could also have relatively good amphibious capabilities as well as good mobility in difficult terrain.

**SWOT analysis**

The following strengths, weaknesses, opportunities and threats with the proposed technology as compared with other unmanned systems within the scenario were identified at the seminar:

*Scenario 1*

*Strengths*

- The weapon has an added ability to defeat a defensive system of a vessel
- Increase torpedo range

[6] Close-In Weapon System

*Weaknesses*

- In torpedo mode the missile might be too slow
- The transition between air and water might damage or destroy it

*Opportunities*

- Adds a measure of unpredictability to a weapon

*Threats*

- The missile might be too heavy or too expensive for practical use

*Scenario 2*

*Strengths*

- The vehicle trades crew-space for payload and mobility
- The vehicle shares parts with existing vehicles

*Weaknesses*

- The system needs maintenance that is specific to the system
- It requires communication with the master system

*Opportunities*

- Can increase the capability of a mechanized unit without increased manning

*Threats*

- Driving in difficult terrain might require a driver using a remote control

**Assessment of capability impact**

Adding the capability to move in two different media might increase the capability for mobility, weapons effect, protection and intelligence gathering of an unmanned vehicle. However, it will also add to the complexity of the vehicle. In order to be able to efficiently move in different types of media the propulsion system has to be as close to optimal as possible for the media in question. Having two different propulsion systems will add weight and complexity to the vehicle, using one propulsion system for different media will make it at least less than optimal in one of the medias. This will affect mobility, maintenance, logistics and reliability. Whether the added mobility from the possibility to move in different media will increase the systems capability more than the added complexity will reduce it is difficult to answer without practical tests of the system in question.

**Assessment of military utility**

Within the analysed scenarios the military effectiveness of multidomain unmanned systems is assessed to be uncertain. This is due to the added complexity of the system which might negate the identified increase in capability.

The military suitability is also uncertain. On one hand, both systems described might share parts and control system with current systems. This might reduce requirement on training and logistics specific to the systems. On the other hand, specifically for the cruise torpedo, getting a system to successfully function as a weapon might be too difficult. An actual product might have too inferior capabilities either in the air or under water to be of practical use. The successful transition between air and water is also a challenge that might be too difficult to solve.

The affordability, too, is uncertain. Designing and manufacturing a system that successfully operates in different media has some challenges that are difficult to predict. In the two scenarios, the latter appears easier to realize since amphibious tracked vehicles are available from several manufacturers.

In conclusion, the military utility of UxS is uncertain and closely dependent on the vehicle and its application.

**Assessment of footprint 2040**

The following list is a compilation of anticipated footprints created by the use of UxS to the factors DOTMPLFI (Doctrine, Organization, Training, Materiel, Personnel, Leadership, Facilities and Interoperability) as well as the demands that are expected to be put on the SwAF R&D in order to facilitate the introduction of the technology.

| **Influencing factor** | **Footprint** |
|---|---|
| Doctrine | Limited |
| Organization | Limited |
| Training | System specific training is required both for operators and maintenance crew |
| Materiel | Spare parts, maintenance, logistics specific to the systems will be required |
| Personnel | Limited |
| Leadership | Limited |
| Facilities | Limited |
| Interoperability | Communication links to control the systems must be compatible |

**Assessment of the need for military R&D**

Most parts exist, implementation requires research.

**Conclusions on military utility and recommendations**

The cruise torpedo in scenario 1 might be a bit too imaginative to be of practical use. Assuming that a reasonably fast torpedo has a top speed in the order of 25 m/s, and a self-defence system has an effective range of about 4 km it would take the torpedo almost three minutes to reach its target. This would leave the target some time to manoeuvre and maybe avoid the torpedo. On the other hand, if two or more cruise torpedoes are fired against a target they could occupy defensive systems both above and below the surface and thus increase the kill probability.

Using an unmanned amphibious infantry combat vehicle together with a manned combat vehicle might increase the capability of a mechanized unit, but the cost of acquiring and operating the unmanned system could be close to that of a manned system. If that is the case it might be better to have one more infantry fighting vehicle.

In both cases the systems are technically feasible, but the main sources of uncertainty are coupled to the added complexity and the utilization of the systems. The pros and cons of the systems appear to be of similar magnitude therefore it is not clear whether they would be more efficient than existing systems.

**Blockchains**
Ref [1] Referee: Marcus Dansarie
Interview: Amund Gudmundson Hunstad, researcher, FOI

*References:*
Ruhlig, K. (2018), *Blockchains*, Fraunhofer Institute, Euskirchen, Germany
Yaga, D. et al. (2018), *Blockchain Technology Overview (NISTIR-8202)*, NIST: National Institute of Standards and Technology, Gaithersburg, United States

## Introduction

Blockchains are based on the idea of connecting blocks of data in a way that enables detection of changes in previous blocks. The connected blocks can be used to construct a ledger in a distributed database. The type and format of the data stored in the blocks varies by application and implementation, but common to all blockchains is that each block contains a hash value of the previous block.

The blockchain technology is presently at TRL 9, and could be utilized today.

A hash value is the output of a hash function, a one-way function that associates any input with a fixed-length output. For a good hash function, calculating the corresponding input for a given hash function output or calculating two inputs that have the same output should be computationally infeasible (i.e. impossible in practice). This property of hash functions is the key enabler of blockchain technology: changing the contents of a block would require changing its hash value stored in the next block and so on.

The primary use of blockchain technology is in contexts where no mutual trust can be established. Bitcoin, a virtual currency and the most successful application of blockchain technology to date, is an example of this. In the Bitcoin protocol, the blockchain serves as a digital ledger that records all Bitcoin transactions ever made. Each block contains a number of transactions. When a transaction has been added to a block that is a certain number of blocks down from the current top block, the receiver can be sufficiently certain that the transaction will be unchanged forever. This allows the protocol to detect double spending, i.e. spending the same money more than once, without relying on a trusted third party database, as is the case in traditional banking.

## Identified possibilities and constraints

The following possibilities and constraints were identified in the report.

Possibilities

- Makes it possible to create and maintain distributed databases without trust between users.

Constraints

- The full ledger of database changes needs to be stored.
- **Suggested military use**
- Verifying the change history of software in critical systems.
- Providing integrity, accountability, and non-repudiation of records handled by many different actors, e.g. in logistics.

## Assumptions

The concept scenario is based on the following assumptions.

- Communication systems exist that can transfer information between blockchain nodes even in the highest levels of conflict.
- Traditional systems, such as databases, do not provide the functionality required in the scenario.

**Concept system and scenario in 2040**

All changes to software components in mission critical systems, such as source code, executables, and configuration files, is stored in a blockchain. An authorized person or organization cryptographically signs each change. This creates a ledger of changes to the software. Using the blockchain, users can always check that the software running in their systems is free from unauthorized changes.

Software verification through blockchain technology also enables new distribution methods for software. The software can be distributed by any means and checked for validity against the blockchain when it is loaded into the system. This ensures that software can be updated quickly in response to new needs on the battlefield.

**SWOT analysis**

*Strengths*
Practically impossible to change information stored in a blockchain.

*Weaknesses*
Requires the entire ledger of events to be stored by multiple users.

*Opportunities*
Homomorphic encryption[7] may remove the requirement that all information in the ledger must be readable by all authorized users.

*Threats*
More established technologies, such as databases and public key encryption, can provide the same functionalities as blockchains in almost all applications.

**Assessment of capability impact**

Negligible.

**Assessment of footprint**

| Influencing factor | Footprint |
|---|---|
| Doctrine | Limited. |
| Organization | Limited. |
| Training | Limited. |
| Materiel | Existing systems must be updated to support e.g. blockchain verification of loaded software and firmware. |
| Leadership | Limited. |

[7] Homomorphic encryption makes it possible to perform certain operations on encrypted data. This can for example be adding, comparing, sorting, or verifying.

| | |
|---|---|
| Personnel | Limited. |
| Facilities | Limited. |
| Interoperability | Common information interchange formats and algorithms are required. |

**Assessment on the need for military R&D**

Limited.

**Conclusions on military utility and recommendations**

While blockchain technology is novel and interesting, it does not yet appear to have found any compelling applications. The only widely successful use to date appears to be Bitcoin and, to some extent, its many spinoffs. Despite the success of Bitcoin, where very large amounts are successfully transferred every day, the system has a number of problems. This is especially true when it comes to scalability and energy efficiency. The US National Institute of Standards and Technology (NIST) has published a Blockchain Technology Overview [2] that highlights many of the strengths and limitations of blockchain technology. Among other things, the publication emphasizes that traditional databases are the preferred solution in most use-cases where blockchains may be considered.

In the concept scenario described above, blockchain technology is used to verify software in mission critical systems. Such a capability would undoubtedly provide utility by enabling new and faster updating of software in combination with the capability to continuously verify the software running on the systems. However, these capabilities are already provided by other technologies. In the case of verifying the source of software, this is most commonly done by signing software binaries using public key cryptosystems or whitelisting the binaries' hash values in the operating system. Source code versioning systems, such as Git, also already provide change detection and source code history through a combination of the same two technologies.

In conclusion, blockchain technology does not currently appear to have any military application or utility that isn't already provided by other, more mature, technologies. It is therefore assessed as having negligible military utility.

**5G technologies in military applications**
Ref [4] Referee: Marcus Dansarie
Interview: Nilsson Jan, researcher, FOI

*Reference:*
Asp, B., Axell, E., Eliardsson, P., Lindgren, T. & Nilsson, J. (2018), *5G-tekniker i militära tillämpningar* [5G technologies in military applications], Totalförsvarets forskningsinstitut (FOI), Sweden

## Introduction

The FOI report on military applications on 5G technologies [1] differs from the other reviewed reports in that it largely describes technologies that are much closer to realization. Fifth generation mobile telephony technology is already in the process of establishment with commercial operation only one or a few years away (TRL 8). Telecom generations are continuously evolving, driven by strong commercial forces. It is not reasonable to aim to predict the nature of the telecom generation by 2040. Based on this, the time perspective in this assessment is the year 2030. As stated in the report, its purpose is to describe some of the technological options developed for 5G and emphasize possibilities for increasing capacity and robustness in military communication systems.

After describing the main scenarios, use cases, and technical realization of 5G mobile networks, FOI's report focuses on a selection of services and technologies that the authors have assessed as possibly interesting in a military context. Two interesting services are described in their own chapters: Mission Critical and Satellite based 5G. The Mission Critical service is a collection of network functions for robust communications. It is aimed primarily at public safety users. Its functionality is similar to that of other public safety systems such as TETRA and P25. The report notes that it could possibly come to replace existing such systems.

Satellite based 5G services use modified versions of the 5G standards to provide high-bandwidth communication of large or remote areas. The report describes ways to achieve this with varying degrees of technical complexity. Similar satellite services based on modified previous generation standards are available commercially today.

After the description of these two services, the report identifies eight interesting technologies:

- Software defined networks (SDN)
- Multi antenna systems
- Self-interference cancellation
- Handling of many multiple users
- Broadband receivers and millimetre wave
- Multiconnectivity with several carriers
- Error correcting codes
- Security architectures

For this forecast, the technologies multi antenna systems, self-interference cancellation, and broadband receivers and millimetre wave were selected for further study. This is because these were initially identified as having the technologies or services with the greatest potential for high military utility.

**Identified possibilities and constraints**

The following possibilities and constraints were identified in the report.

Possibilities

- The multi antenna systems for handheld devices developed for 5G could also be used on other small devices. This would give the same benefits as on 5G phones: lower power consumption, longer range, and resistance against intentional and unintentional interference.
- For military users, multi antenna systems in combination with millimetre wave frequencies could significantly lower the probability of intercept, which would be a large advantage.
- Self-interference cancellation (SIC) enables simultaneous transmission and reception on the same frequency through efficient cancellation of the transmitted signal in the reception path. In theory, this means that a system with SIC could use half the bandwidth compared to the same system without SIC.
- Self-interference cancellation could also have applications in the radar and electronic warfare fields. It is possible that this technology could significantly improve performance compared to existing systems. In electronic warfare, SIC could enable use of a platform's own sensors while jamming. This includes evaluation and adjustment of jamming in progress.

Constraints

- One of the main advantages of the technologies studied here is that they are developed for 5G mobile telephony applications. Low prices and high availability of components presumes that they are developed and mass-produced for those telephony applications. If 5G technologies for military use must be developed specifically through military R&D, the numbers of produced systems could demand prohibitively high R&D costs.

**Suggested military use**

- Close range communication systems with high availability and low probability of intercept.
- Electronic warfare systems.

**Assumptions**

The concept scenarios are based on the following assumptions.

- The technologies developed for 5G technologies can be adapted to military applications without requiring large additional research and development efforts.

**Concept systems and scenarios in 2030**

The Army's new personal radios for soldiers incorporate technologies and components developed for 5G telephony. The new radios use millimetre wave frequencies and have multi antenna arrays. The new technology has provided several advantages. Compared to previous generations of radios, the new ones have much better resistance to both intentional and unintentional jamming. The millimetre wave technology has also enabled higher data rates, which has made it possible to share sensor data in real time. In urban environments, this is complemented by the radios' mesh networking capabilities, which ensures that soldiers can talk to and send data between each other even when they are inside large buildings. The increase in the ability to communicate has consequentially led to an increase in situational awareness for soldiers, leaders, and commanders.

A new generation of electronic warfare systems have been introduced in air force fighters. The new systems incorporate technologies and components developed for 5G telephony. This includes self-interference cancellation capabilities. As part of an attack mission, the fighters use the electronic warfare systems to jam and suppress enemy air defences. The SIC capabilities mean that the fighters can still use their own radars, even though they use the same frequency band as the jammed enemy radars. The SIC also enables the jammers to evaluate the efficiency of the jamming and follow the enemy radar's frequency changes – all while jamming at full power. Together, this enables the fighters to maintain full situational awareness, while denying the enemy the same.

**SWOT analysis**

*Strengths*

- Multi antenna systems for personal equipment may lead to improved communication abilities at the soldier level.
- Self-interference cancellation technology has potential to increase performance in electronic warfare applications.
- Some components are relatively cheap, thanks to mass-production for telephony applications.

*Weaknesses*

- Short lifecycles and discontinued manufacturing of components.
- Components and technologies developed for 5G applications may not fill requirements for military applications.

*Opportunities*

- Multi antenna arrays and millimetre wave frequencies may have synergy effects with mesh networking technologies.

*Threats*

- High-bandwidth communications technology provide too much information to too many soldiers, thereby impeding the required tactical agility through a sort of information overload.

**Assessment of capability impact**

Provided that adaption to military applications is successful, the 5G technologies may provide moderate to significant improvements to the performance of electronic warfare systems and soldier-carried personal communication systems.

**Assessment of footprint**

| Influencing factor | Footprint |
|---|---|
| Doctrine | Limited. |
| Organization | Limited. |
| Training | Training will likely be necessary for military units to fully take advantage of new capabilities. |
| Materiel | Introduction of 5G technologies will likely come with new generations of military equipment. |
| Leadership | Limited. |
| Personnel | Limited. |
| Facilities | Limited. |
| Interoperability | Limited. |

**Assessments on the need for military R&D**

Adaption of 5G technologies to military applications requires R&D.

**Conclusions on military utility and recommendations**

The cutting edge in the microwave domain has previously been dominated by development for military purposes. Research and development for civilian telecommunication systems is now competing for the lead in this field. Since the telecommunication market is much larger than the market for military microwave equipment, this will likely bring with it large reductions in cost. This will not only be because of a much larger market for components, but also because of spillover effects from R&D for telecommunications purposes.

Some of the technologies developed for 5G mobile telephony networks have military applications. This includes those identified in the FOI report. It is likely that components and technologies that are suitable for military and aerospace applications will be used by manufacturers of such equipment as soon as they are available on the market. 5G technologies are assessed as having a potential for moderate military utility.

## Reflections on the method

Our evaluation of the method used shows that there is a risk the assessment is biased by the participating experts' presumptions and experiences from their own field of research. The scenarios that were chosen do not cover all aspects of the technology and their possible contribution to operational capabilities. It should be stressed that we have assessed the six technologies' potential military utility in the presented scenarios, not the technology itself.

The chosen definition of military utility clearly affects the result of the study. The definition is the same that has been used in the Technology Forecast since 2013. It is seen as being sufficient for this report, but could be further elaborated in the future.

The greatest value of the method used is its simplicity, cost effectiveness and the trade-off that it promotes learning within the working group. The composition of the working group and the methodology used is believed to provide for a broad and balanced coverage of the technologies under study.

This report provides an assessment of the military utility of some emerging technologies within identified relevant scenarios. It is intended to contribute to the SwAF Headquarters' evaluation of emerging technologies.