Technical Evaluation Report (TER) IST-200

Research Symposium (RSY)

INTERNATIONAL CONFERENCE ON MILITARY COMMUNICATION AND INFORMATION SYSTEMS 2023

Skopje, North Macedonia

16 and 17 May 2023

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1.0   OVERVIEW

This Technical Evaluation Report (TER) provides a summary record of the major technical outcomes of the International Conference on Military Communication and Information Systems (ICMCIS) held 16th and 17th May 2023 in Skopje, North Macedonia. The conference was sponsored by the General Mihajlo Apostolski Military Academy.

As this was the first time that ICMCIS was held as a formal STO event, this TER also provides a considerable analysis of the organisational and administrative aspects, in order that the lessons from these can be captured and future conferences be improved.

The theme of the conference for 2023 was selected to be: "ICT-solutions for Multi Domain Operations". Within this theme, papers covering a variety of technical specialisations were solicited, including data related topics (big Data, Artificial Intelligence, and Machine Learning), Cyber Security, Networking, Wireless Communications, Architecture, Quantum technologies, etc.

The conference call for papers resulted in 59 paper submissions, of which 29 were rejected, giving a very high-quality standard for the conference. Of the rejected papers, seven were accepted for 'quick fire' (3-5 minute) presentations followed by a poster session. Only the 30 accepted papers were submitted for publication in IEEE Xplore. In addition, the conference included four keynote addresses, covering both military operational challenges and perspectives and technical advances.

Overall, the assessment is that ICMCIS was highly successful, shared significant research results, identified a number of potential future research directions of military significance and was very well appreciated by authors and attendees. Overall, the conference was well organised, well executed and accomplished its aims. The various chairs, organising committees, the Host Nation, and the CSO should be congratulated for their excellent work before and during the conference.

2.0   ORGANISATION OF TER

The TER is structured as a series of Annexes so that the reader can find and read only the portions of most interest to them. For example, Annex A covers the technical aspects of the conference, providing a summary

of the content of the conference as well as the technical conclusions and recommendations. Further content detail can be found in Annex C, which provides abstracts of all papers and posters and summaries of keynote addresses, while Annex D provides detail of analyses made. Similarly, Annex B provides a summary of the administrative and organisational aspects, along with associated conclusions and recommendations.

Overall, the TER is organised as follows:

- This covering section provides an overview of the organisation of the TER.
- The remainder of the report is organised into a number of Annexes.
  - Annex A provides an executive summary of the technical content of the conference and provides the technical conclusions and recommendations.
  - Annex B covers the organisational and administrative aspects of ICMCIS. It also provides an historical overview of the conference documenting how things were organised in the past and the changes that were introduced for 2023. It provides conclusions and recommendations regarding the administrative & organisational aspects.
  - The next annex, Annex C, provides abstracts of all papers and posters presented at ICMCIS. It also provides summaries of the keynotes and some of the industrial presentations.
  - Annex D provides a summary of various analyses made regarding technical content, attendee demographics, and feedback received from participants via the post-conference questionnaire. Any conclusions and recommendations made from these analyses are brought forward to the appropriate Annex: A or B.
  - Annex E provides lists of individuals who constituted the Steering Committee, the Core Team and the Technical Programme Committee.
  - Annex F, for posterity, provides a chronological history of the ICMCIS conference, identifying where it was held, who were the sponsors and what high-ranking NATO individuals were in attendance and other information considered historically significant.
  - Annex G provides a list of keywords that reflect the technical content of ICMCIS 2023.

Annex A – EVALUATION REPORT – TECHNICAL

A1.0   SUMMARY

ICMCIS 2023 was held in Skopje, North Macedonia, on 16 and 17 May 2023.

The theme of ICMCIS 2023 was: "ICT-solutions for Multi Domain Operations". Within this theme, papers covering a variety of technical specialisations were solicited, including data related topics (Artificial Intelligence for Military Decision Support, Big Data Analytics and Visualisation, Scarce Data, Counter / Adversarial AI), Robotic Process Automation, Augmented and Virtual Reality, Data Centric Architecture, Distributed Resilient Infrastructure, Internet of Military Things, Homomorphic Encryption, Quantum Safe Cryptography, ICT Supply Chains, EM Spectrum Management & Sharing, C4ITest Beds, and Ethical, Legal, Societal and Environmental Aspects.

The technical content of the conference was exceedingly high, with 30 full papers being presented as well as seven posters, four keynotes and four industrial presentations. Papers were grouped into seven themes: AI and ML, Transmission and Antenna Systems, Tactical Networks, Data and Information, Cyber Security, Quantum Information Systems, and Software Defined Radio. ICMCIS was attended by approximately 120 persons.

In their keynote addresses, the CSO Director and UKR speakers both emphasized the need to consider Multi-Domain Operations (MDO) in everything we do. They discussed the need for technology, organizational, and cultural changes, as well as the importance of data, AI, and ML as we move to data-centricity and MDO.

The conference heard about some novel approaches to handling data in the presence of limited communication channels, such as the use of data grids. There were considerable contributions to the development of communication solutions, including discussions of challenges and solutions in the tactical domain. The topic of Next Generation Communication Systems was covered in one of the keynotes, emphasising the current thinking surrounding 6G, the opportunities presented by commercial space-based communications as well as federated learning as a way of minimising demands on scare bandwidth.

The agility of commercial technology and processes was emphasised; for example, how hackathons can provide prototype solutions in a matter of days. Ukraine discussed what they have been able to accomplish in stressed timelines, providing rapid and relevant support to the war fighters, enabled by the adoption of commercial development processes and open-source solutions and software.

The event provided coverage of several EDTs: quantum, big data, AI, next generation communication systems and related topics. Quantum had several interesting presentations, covering significant military use cases of quantum information systems, quantum key distribution, and quantum signatures. Big data and AI were discussed in two tracks, plus a very dynamic keynote presentation. The challenges of fake news and disinformation were highlighted. Disinformation is considered a very challenging topic, but significant in its potential to disrupt and influence our Western democracies. Cyber, trust, and related topics were also addressed.

Industrial topics were presented by four local North Macedonian industries. ATS Group, which produces ballistic products such as vests, helmets, and plates, and has a significant capacity to produce ammunition. Kernel Group presented on digital transformation and cyber security also demonstrating a significant capability in these areas.

A1.1 Stated Aims and Military Significance

The aims for ICMCIS established in the Technical Activity Proposal (TAP) were:

- Provide a forum to identify and gain input on and resolution of issues associated with NATO Consultation, Command, Control (C3) Policy and the IST-panel Programme of Work (PoW);

- Provide overviews of current NATO C3 activities pertaining to both the development and effective employment of ICT-solutions;

- Highlight IST impact assessments and lessons learned; and

- All papers will be peer reviewed i.a.w. IEEE review guidelines. Papers will be judged on military relevance and significance, scientific value, originality, and technical quality. Only papers that meet the criteria will be accepted. Papers related to IST-activities that do not meet the criteria and are rejected, will have the opportunity for a poster presentation.

The military significance identified in the TAP for ICMCIS were:

- The Conference covers four of NATO's EDT's: big data, quantum, AI and cyber. Since civil developments are driving the innovation of Information and Communication Technology (ICT), also for the military, these are most relevant to this symposium. At the same time the military has unique technical challenges that the commercial sector will not address as it will increasingly: (i) engage in distributed operations in complex settings, (ii) operate with extreme resource constraints (communications, computational, and size-weight-power-cost-time). The symposium covers all aspects of information provisioning and processing: from communication and networks to cyber, cloud, quantum, applications, and artificial intelligence. It therefore forms the basis for the IST technology scan, new TAPs, and international collaboration. The broad international reach of this symposium is essential to achieve a global perspective of research in CIS and emerging and disruptive technologies, necessary to contribute to Emerging Disruptive Technologies (EDT) tasks on technology trends and risks.

- To reflect the military relevance, each year a theme is selected. The theme for ICMCIS 2023 was "ICT-solutions for Multi Domain Operations".

A1.2 Scientific Overview

The major scientific results presented during ICMCIS, as either full papers or posters, are summarised here under seven themes, which closely follow the structure of the conference tracks. The abstracts for each paper and poster presented during ICMCIS are found in Annex C. Additionally, summaries of the keynote presentations and a selection of the industrial presentations are also included here.

Theme 1 – Artificial Intelligence and Machine Learning

The AI and ML theme touched on a number of interesting and military relevant topics: the ability of publicly available language models to generalize to the NATO context, the intrinsic performance of transformer models for Natural Language Processing (NLP) tasks on domain-specific text, the potential definition and application of robustness criteria for machine learning systems, a proposed analysis and tracking dashboard for recognising disinformation, a spatio-temporal memory density clustering for battle space object aggregation, a visual analytics tool for activity based intelligence, and the evaluation of metrics for autonomous decision making.

Theme 2 – Transmission and Antenna Systems

Major scientific contributions presented included: the development of techniques to manage self-interference and crosstalk in full-duplex communication systems, the potential of free space optical communications in

military use cases, the analysis of link performance degradation from interferences in military networks, the physical limits for in-band full duplex in frequency-hopping tactical radio systems, the potential of 5G O-RAN for military communications, sub-block turbo equalization for CPM waveforms in multipath environments, and the DOTMFLPI analysis of 5G for several military use cases. Additionally, also discussed was an assessment of the antenna mounting location on a military vehicle for jamming applications based on computational electromagnetics, the calibration of multi-robot coherent beamforming, and the design of high-isolation Yagi-Uda antennas for military full-duplex radios at 300 MHz.

Theme 3 – Tactical Networks

The presented papers stressed the importance of improved data sharing and processing capabilities in disadvantaged networks at the tactical edge of coalition operations. The major scientific contributions included: A system architecture for federated and adaptive clouds that can be deployed in tactical networks; Combat ICT systems and their use of communication resources for more effective military operations; Distributed information exchange and policy routing across a mixture of military and civilian carriers; Adaptive user-facing services and cross-layer optimization to react and adapt to underlying network changes; Mobility prediction methodology applied in a handover mechanism to minimize packet loss and maximize time connected to centralized control; Limitations in optimizing the routing protocol in ad hoc mobile networks; and Federated and adaptive clouds for disadvantaged tactical networks to enable improved data sharing and processing capabilities between mission coalition partners.

Theme 4 – Quantum Technologies

The major scientific themes found in the two papers were: the potential of quantum computing technology for military operations, the development of new cryptographic mechanisms to protect against the threat of quantum computers, and the implementation of a quantum-safe digital signature protocol in a simulated environment. The papers also discussed the applicability of quantum digital signatures in multi-domain operations and the use of the protocol to confirm orders along the command chain.

Theme 5 – Data and Information

The major scientific themes presented were: the use of tactical edge networks for adaptive information dissemination, data-centric consultation, command and control, data mesh approaches for enabling data-centric applications at the tactical edge, exposing military sensor data using spatiotemporal asset catalogues, and non-line-of-sight ranging via ultraviolet signals. These themes focused on the use of data-driven approaches to improve situational awareness and decision-making in military operations, as well as the development of technologies to enable data-centric applications in challenging environments.

Theme 6 – Cyber and Security

The contributions of the papers grouped under this theme were: the development of new Visual Analytics systems for the detection of Advanced Persistent Threats (APT), the use of Multi-Agent System for Advanced Persistent Threat Detection (MASFAD) framework and the combination of highly-detailed and dynamic visualization techniques to define sophisticated cyber threats. Additionally, the papers discussed the use of virtual laboratories for experiments with cyber security functions in coalition networks, the implementation of security function virtualization to support/speedup network topology changes, the deployment of two chains of virtualized cybersecurity functions at lower and higher protocol layers, and the development of autonomous cyber defence capabilities for Protected Core Networking (PCN).

Theme 7 – Software Defined Radio

The major scientific themes presented were: the development of interoperable waveforms for software defined radios (SDRs) to enable coalition forces to exchange tactical and mission critical data on the battlefield, the evaluation and optimization of physical layer waveform implementations for SDRs based on over-the-air measurements in mobile scenarios, the implementation of a low complexity generic receiver for narrowband and wideband HF, the use of game-theoretic approaches to attack planning and controller placement in software defined networks (SDN), and the coordination of the SDN and TDMA planes in software-defined tactical MANETs with adaptive coding and modulation. All of these themes are of military significance, as they are aimed at improving the communication capabilities of military forces.

NATO Keynote – CSO Director, Mr John-Mikal Størdal

The CSO Director emphasised the importance of the ICMCIS conference, the largest European conference on Military CIS matters. He also welcomed the non-NATO partners such as Ukraine and Singapore. He noted that ICMCIS provided and excellent opportunity for sharing of Information Systems Technology (IST) Panel results but also could be used for sharing beyond the IST Panel to a wider community. The emphasis placed during ICMCIS on encouraging the next generation of scientists was also noted and welcomed.

He discussed the 'technological edge' stressing the importance of having access to the best weapons and technology, noting that the war in Ukraine is a seismic shift. He discussed the importance of investing in Science and Technology (S&T) to maintain the technical edge, noting that it is more important than ever before. He noted that S&T is the cornerstone of being able to deter and defend, and discussed the opportunities that exist in sensor technology and how AI and ML can help to leverage enormous data sets that are produced by new sensors. He emphasised the importance of collaboration and how the Collaborative Programme of Work (CPOW) is an efficient model that supports these aims. He noted that CPOW is executed by the largest S&T network in the world, bringing together the best minds to find solutions. The Director mentioned the Defence Innovation Accelerator for the North Atlantic (DIANA) as an important development as it brings new opportunities and new partners to the table. He discussed the need for pragmatic solutions, involving rapid prototyping and experimentation.

The Director stressed the importance of the emerging concept of Multi-Domain Operations (MDO), which aims to connect five domains of operations (Land, Sea, Air, Space and Cyber) in and amongst each of the 31 nations. He noted that this is a huge challenge but also that it is urgent given the need to fuse Space and Cyber Defence, as well as non-military players such as NGOs and civilian organisations. He also discussed the need for cultural change in NATO and the Nations to make MDO successful. He then discussed the need to get inside the decision loop of our adversaries by facilitating faster and higher quality decision making and how AI and ML can support this. He discussed the promise of quantum technologies, which he stressed can only be leveraged through cooperation.

He concluded by emphasising again that ICMCIS is key to maintaining the technological edge, as it creates a forum for sharing and disseminating information and identifying new collaboration opportunities.

Operational Keynote – Ukraine Delta Team

Maj Yelyzaveta Boiko and First Lieutenant Dmytro Teslov of the Delta Team from the Ukraine presented an Operational Keynote regarding their Delta family of C2 tools. These tools provide Situational Awareness (SA) and Common Operational Picture (COP) functions, Ballistic Calculations, Intelligence, Secure Chat, Geographic Information Systems, a Wiki, and the ability to consume Drone feeds, videos streams, file sharing, and commercial data providers. Importantly, they discussed not only the product's capability, but also their development approaches and architecture, covering aspects of People, Processes and Technology.

The Team discussed their use of Agile development methodologies to develop and subsequently quickly adapt the DELTA tool set to new or changing operational situations and to continually enhance capabilities. This methodology embraces commercial approaches to improve speed of delivery.

The Delta Team also discussed the concepts of accessibility, reusability, and safety. The tools run in the cloud and use NATO standards, providing interoperability between sensors and weapons systems. The Delta Application has a three-stage pipeline: ISTAR, responsible for ingestion, aggregation, verification and further dissemination of data; a Common Operational Picture to provide situational awareness; and distribution of information to operators, commanders, brigades, artillery, drones, etc. Multi Domain Operations (MDO) is baked in from the outset in the thinking and design.

The Team relies on open-source software and implements a zero-trust framework. They use UKR National Digital Passports to authenticate users and have strict access control of information, by data element, hiding source information. The applications are implemented in the Cloud and rely on a Bring Your Own Device (BYOD) approach (tablet, smart phone, laptop), providing both custom APP forms of tools and web interfaces. Delta relies on a combination of both military and civil as well as terrestrial and satellite (i.e. Starlink) systems for communication. Cyber security employs Mobile Device Management (MDM), a physical token (FIOD-2), EDR Endpoint Detection and Threat Response, and is regularly penetration tested (PenTest) to ensure security. Recently, the application withstood a significant Distributed Denial of Service (DDoS) attack.

In closing, the presenters extrapolated the future as a war of machines, where cyber defence would be paramount, routine work would be automated, and more sources of information would be available and included. They concluded by providing the following key insights:

- Learn from the best- do not reinvent what is working;
- Keep standards in the core, but be flexible;
- Use as much from commercial and open source as you can;
- Navigate the changes, don't follow;
- MDO first thinking;
- Validate your ideas on the battlefield, ASAP;
- Horizontal communications are key;
- Build a network of innovators;
- Lessons learned need to become lessons applied; and
- Keep fighting for a better future.

The audience gave the Delta Team a standing ovation reflecting the acknowledgement of the pressure they are under, and the admiration for what they had achieved in a very compressed timescale.

Scientific Keynote 1 – Professor Popovski

Dr Popovki's presentation covered a topic of high interest to NATO; that is, the topic of the most recently identified NATO Emerging and Disruptive Technology: Next Generation Communication Systems.

At the address, Professor Popovski discussed the evolution of 5G to 6G, and the revival of satellite connectivity. He explained that 6G will add intelligence learning, localisation and sensing to the standard communications model of 5G, which was focused on enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC) and massive Machine Type Communications (mMTC). He discussed the potential of the Internet of senses, perceptions of time, the value of information, and the

convergence of satellite and terrestrial networks. He also discussed the different types of satellite orbits, such as LEO, MEO, GSO, GEO and HEO, and the revolution that was happening in space due to the orders of magnitude lower costs of launches and miniaturisation of space craft. He also discussed the use of Reconfigurable Intelligent Surfaces (RIS) as reflectors to reradiate signals in desired directions, and the use of federated learning to address issues of privacy, unbalanced data sets, and massively distributed data sets. He concluded by noting the rekindled interest in satellite connectivity, and the need to rethink distributed algorithms for federated learning. He also highlighted the many new research problems that need to be addressed, such as distributed algorithm design, satellite IoT, and Edge computing with satellites.

Scientific Keynote 2 – Professor Chris Reed

Professor Chris Reed presented a very entertaining and thought-provoking keynote based on the work undertaken by him and his team at the University of Dundee concerning Argumentation Theory.

Professor Reed covered the theoretical aspects and the problems he was trying to solve indicating that the 'holy grail' was to be able to analyse, in real-time, oral debates and extract automatically the argumentation being used. The theory involved developing and standardising a framework that could be used to capture elements of argumentation discourses in a systematic and unambiguous way facilitating further analysis.

Dr Reed stressed the importance of having a multidisciplinary team, including individuals with backgrounds in philosophy, linguistics, artificial intelligence, computer science, etc.

Dr Reed discussed several examples of where he has used the technology to support organisations such as the BBC and others to help analyse topical debates or support students in improving their argumentation skills.

One interesting aspect was that it appeared to be feasible to identify a particular individual from the specific way they engage in a dialogue. Another interesting aspect of Dr Reed's work was its applicability to automated identification of disinformation and fake news.

The presentation was well received, and the technology could certainly be of value supporting committee meetings and other consultation fora in NATO or similar organisations.

Industrial Presentations

The TER Author had the opportunity to listen to two of the four Industrial presentations. One was by the ATS Group, who produce ballistic products (vests, helmets, plates) and ammunition (small arms through to heavy artillery/tanks). Although the topic was not immediately relevant to the IST Panel, the presentation nevertheless generated interest as Nations are feeling supplies of these products getting tight due to their continued support to Ukraine. ATS Group emphasised that their production capacity is being scaled up rapidly to deal with the surge in demand. The other presentation was by the Kernel Group, a Romanian based company with a footprint in North Macedonia, who focus on digital transformation and cyber security. They clearly had a depth of knowledge in these specialist domains and could be significant contributors to NATO or its member nations.

A1.3   Technical Conclusions and Recommendations

The following major technical trends were identified as significant:

- Multi-Domain Operations is urgent and needs to be considered in everything we do. This will require technology to make it a reality, including AI and ML. It will take new thinking in the cyber domain, to ensure adequate protection and it will involve cultural changes in both our technical and operational staffs. The importance and value of Data, AI, ML as we move to Data-Centricity and MDO was also stressed during the conference.

- **Recommendation** [T1]: Set up a cross disciplinary/cross panel exploratory team (ET) to examine current operational thinking regarding MDO and define a series of TAPs to address the most urgent needs. Incorporated in these TAPs should be concepts for rapid prototyping and experimentation in order to progress concepts rapidly and pragmatically.

- **Recommendation** [T2]: Going forward, in each new TAP, under the military relevance assessment, ask authors to include a statement regarding relevance of the proposed work for MDO.

- MDO was the established theme for the conference. Nevertheless, of the accepted written papers only two explicitly mentioned MDO. Two of the keynotes highlighted the importance of MDO going forward. Nevertheless, the relevance of many other papers to MDO could be argued but was not made explicit.

    - **Recommendation** [T3]: If a theme is to be used, authors should be encouraged to submit papers dealing with the theme, and as a minimum, to mention the contribution of their paper (if any) towards the theme.

    - **Recommendation** [T4]: If themes are to be used and are to steer directions of research, then perhaps a one-year horizon for themes is too short. If themes are to be used in the future, it is recommended that a rolling list of themes for the subsequent three ICMCIS conferences be created, based on NATO/CSO research priorities, and made widely available so that authors have time to blend this into their funding requests and research programmes.

- US DoD authors encountered delays to get papers approved for public release. This had knock on effects in terms of the smooth execution of the overall conference preparation schedule. It is expected that this issue will continue in 2024 and beyond for the US DOD. General guidance received by US DoD authors has been to limit military relevance and speak to scientific contributions.

    - **Recommendation** [T5]: Early in the 2024 ICMCIS cycle, convene a small group to examine this issue and make recommendations as to how to proceed in regard to US DoD authors. Options might include including a controlled session which would, however, limit distribution in IEEE; or dropping or reducing the requirement to indicate military relevance of the papers, contrary to recommendations T2 and T4.

- We saw some novel approaches to handling data across limited channels such as Federated Learning and Data Grids. Federated learning was discussed in the conference in the context of next generation satellite communications. As federated learning can minimise the amount of data that needs to move around the network, it may also have applicability in tactical situations / disadvantaged networks. This is also where data grids may play a role.

    - **Recommendation** [T6]: Consider establishing an ET to examine the possibility of creating one or more TAPs dealing with federated learning in tactical situations.

- Fake news and disinformation continue to be challenging and urgent topics as they can have significant impacts on society if unchecked, perhaps even able to disrupt/influence our Western democracies.

    - **Recommendation** [T7]: While it is understood that one RTG is ongoing on the topic of disinformation/fake news, it is perhaps wise to consider others, in particular working with Dr Reed's team to look at leveraging his work to provide a technology demonstrator to address this urgent need. Working with the NATO HQ Public Affairs Office, who are already pursuing creation of an open-source intelligence (OSI) capability, might be fruitful.

- Next Generation Communication Systems is now a NATO EDT. The value of Starlink in battle was touched on by the UKR Delta team with the technical aspects discussed by Dr Popovski. While some work is ongoing in this area within the STO, this appears to be a technology that has yet to really be understood and exploited as a military capability. Issues such as availability, vulnerability, resilience, security, congestion, commercial models to ensure access at times of need, etc., should be addressed.

- **Recommendation** [T8]: Establish an ET to identify several TAPs for RTGs that will define the military use cases, the opportunities and the vulnerabilities of relying on these constellations in future operations.

- The agility of commercial technology and processes was made clear in the UKR Delta Team's presentation, where we heard what they have been able to accomplish in stressed timelines, providing rapid and relevant support to the war fighters. This was again apparent in the presentation regarding hackathon results addressing dashboarding for disinformation analysis [Paper 6599]. There is still a feeling of distrust of Open-Source software in many cases, particularly when employed on classified networks and data.

  - **Recommendation** [T9]: establish an ET to examine the use of Open-Source software with the aim that a set of standards and norms could be developed that would minimise the risk involved. These could be codified in a 'NATO Open-Source Guidebook', that would address processes on how developers can safely use Open-Source software. Examination of the concept of an 'Open-Source Software Clearing House' might be considered, that could be used to rapidly certify Open-Source software, on behalf of NATO and Nations, for military use.

- Paper 4494 presented a number of IST related use cases for Quantum technologies. With this catalogue, it appears that we have a good starting point to dig deeper into the military use of Quantum Information Systems (QIS).

  - **Recommendation** [T10]: establish an ET to consider which identified use cases are the best candidates for short-term collaborative research and establish one of more TAPs to pursue these.

- The TER Author had the opportunity to listen in to two of the Industrial presentations. One was by the ATS Group, the other by the Kernel Group. Both teams clearly had a depth of knowledge in these specialist domains and could be significant contributors to NATO or her member nations.

  - **Recommendation** [T11]: Although rather poorly attended, the industrial presentations were of value and contributed to the overall success of ICMCIS. Consideration should be given to continue these in the future, perhaps with a focus on the conference theme or conference topics.

- The mix and topics covered by the keynote speakers were a perfect addition to ICMCIS, providing context, as well as educating attendees on new developments which may provide significant military benefits.

  - **Recommendation** [T12]: keynote presentations, following the template used in ICMCIS 2023 (one NATO scene setter, one operational scene setter, and two technical keynotes) should be continued in the future.

- A mapping exercise between the scientific and technical topics for the conference identified in the TAP, in the CfP and the resulting conference tracks revealed that the papers were not providing complete coverage of the aimed topics. The details of this mapping can be found in Annex D. The following observations are made regarding the overall mapping of papers to topics:

  - The bulk of the papers (14 papers + 3 posters) fall into the traditional communication areas, including Software Defined Radio (4 papers), Tactical Networking (3 papers + 1 poster), Antennae (2 papers) and Transmission (5 papers + 2 posters). An additional two papers addressed antenna systems;

  - Pure Cyber Security papers were perhaps too scarce with only four in evidence, 3 regarding conventional Cyber Security and one as an application of Quantum techniques;

  - AI and Big Data were well represented with 4 papers and 2 posters, and also were part of other papers, as a supporting element in other areas of research;

- Architectural issues as well as data-centricity were addressed in five papers, with two addressing directly issues of data-centricity;

- Quantum topics were addressed in two papers, one already mentioned in the context of Cyber Defence, and the other as a more general overview of Quantum Computing / Information Services;

- Information and Cognitive Warfare attracted one paper, while Electronic Warfare attracted one paper and one poster. Community of Interest Services attracted a lone poster paper;

- Robotic Process Automation; Scarce Data; VR/AR/XR/Tele-existence/Real Avatars; Internet of Military Things; Counter / Adversarial-AI and AI for Cyber; Homomorphic Encryption; ICT Supply Chain Security; C4I Test Beds and Modelling and Simulation of Information Infrastructures; and Ethical, Legal, Social and Environmental Aspects of Technology Design / Human Machine Teaming were not covered at all (the list is longer if one uses the topics listed in the TAP); and

- **Recommendation** [T13]: While efforts have been made with some success over the last several years to diversify the conference and include topics other than traditional communication topics, the evidence is that these topics still garner the bulk of the accepted papers. If the topics that are not covered, or only had limited coverage, are truly CSO/NATO priorities for research an investigation should be undertaken as to whether these are being addressed but not being reported through ICMCIS or are not happing at all or not with sufficient focus. Depending on the result of the investigation, additional TAPs could be raised to address any shortfalls in areas that are underrepresented.

- **Recommendation** [T14]: Without diminishing the coverage of communication topics, continuing efforts should be made to diversify the conference to address other topics related to military CIS.

- Feedback from attendees raised some interesting potential topics that might be considered for future TAPs. The suggested topics included: Information Fusion, Security of AI, Data Centricity, Space and SatCom, Cryptography, Command and Control.

  - **Recommendation** [T15]: The IST Panel should consider whether these topics could be potential candidates for future ETs or RTGs. They might also be thought of in combinations, such as Data Centric Command and Control or security challenges of data centricity.

Annex B – EVALUATION REPORT – ADMINISTRATIVE / OPERATIONAL

B1.0   INTRODUCTION

This section of the TER documents discusses the ICMCIS 2023 conference from an organisational/administrative standpoint. The organisation aspects are important in order that lessons are captured regarding how the conference was led and run, so that in follow-on years improvements can be made and continuity provided; lessons will not have to be re-learned. The intent should be to establish an ICMCIS body of knowledge that can be leveraged in future years, and thus reduce the burden on the future organisers. As 2023 was a transition year, where the conference moved from a somewhat ad hoc organisational construct to a formal STO event, capturing lessons learned in this regard is considered particularly important.

In the next section we provide a historical overview of the conference documenting how things were organised in the past and the changes that were introduced for 2023. Further historical details are found in Annex F.

The following section details the conference aims and theme, including a discussion of how and why these were selected.

The third section provides a detailed overview of the organisational and administrative aspects of the conference, including an evaluation of how effective and efficient these were.

The final section summarises the administrative and organisational conclusions and makes recommendations for future ICMCIS (or other RSY type) events.

B1.1   History and Organisation

The International Conference on Military Communication and Information Systems (ICMCIS) is the largest scientific/technical conference in Europe on military CIS. ICMCIS has a long history, its roots going back some 31 years to just after the Berlin Wall came down. It began as a National Conference organised by Poland at their Military Communications Institute (MIŁ) in Zegrze, outside Warsaw. In the mid-90's, with the imminent expansion of NATO to include Poland, The Czech Republic and Hungary, the conference was recognised as an important opportunity to bring the scientific communities of the existing NATO nations and the candidate new Nations together, in order to increase further understanding, scientific collaboration and integration.

Thus, in 1997, the conference was attended by senior representatives of the newly formed NATO Consultation, Command and Control Agency (NC3A). The following year, the conference was given a regional mandate – Regional Conference on Military Communication and Information Systems (RCMCIS). In 2002, the Director of the NATO Research and Technology Agency (RTA) (Ken Peebles) attended and thus began an association with the broader Scientific Community. The conference was also supported by the Defence Investment community with attendance by Assistant Secretaries General for Defence Investment in 2006 (Marshall Billingslea), 2007 and 2008 (Peter Flory). The conference has also been attended by the Director HQ C3 Staff (MGen Glynne Hines), the Chair of the NATO Research and Technology Board (Dr Robert Walker), the General Manager NC3A (MGen George D'Hollander), Directors of the CSO (Mr Allan Schafer, Dr Pavel Zuna, Mr John-Mikal Størdal) as well as NATO Chief Scientists (MGen Albert Husniaux, Dr Thomas Killion, Dr Brian Wells) throughout the years. The conference has also been supported by the European Defence Agency for many years, with a senior representative of the EDA normally giving a

keynote address. From 2006 until 2013 the conference was known as the Military Conference on CIS (MCC). Since 2015 the conference has been known under its current name, the International Conference on Military CIS (ICMCIS). Since 2016, the conference has been held in conjunction with the Spring IST Panel Business Meeting.

In short, the conference is well established, has a long history of association with NATO, and in particular with the NATO scientific communities, as represented by the Scientific and Technology Organisation (STO) and the NCIA and their predecessor organisations.

Over the years, a structure to the organisation of the ICMCIS evolved (although it was never formally documented). It was structured around several key roles and committees:

- A Steering Committee (SC), mandated to make all high-level decisions regarding the conference, including agreeing locations, conducting the final paper selection, agreeing conference themes and topics, support the organisation of keynote speakers, etc. The SC members were generally members for a number of years, which helped provide continuity.

- An overall Chairman of the SC, who provided a day-to-day oversight and support of the conference, making sure that knowledge was passed down and that key events in the annual planning cycle took place;

- A technical programme committee (TPC), mandated to collect paper submissions and conduct the paper peer review, organise the technical programme, etc.;

- A Chair of the TPC, coming from the hosting nation or organisation, that ensured that the mandate of the TPC was carried out. It was usual to have a deputy TPC Chair, coming from the nation or organisation that had agreed to host the conference the following year, in order to gain experience ahead of time. The TPC Chair also acted as the overall Conference Chair;

- A local staff, from the hosting organisation or nation, to provide a venue, organise social events, provide hotel recommendations (at potentially preferential rates), handle conference registration, collection of conference fees, publication of the proceedings with the IEEE or other channels, etc.;

- An awards committee, tasked with identifying the overall conference best paper and the best paper by an Early Career Scientist (ECS). This activity involved choosing candidate papers based on the peer review and then joining each applicable session, where candidate papers were presented, to assess the quality of the presentation and question and answers;

- NASK in Poland provided support by providing design and hosting services for the ICMCIS.eu web site; and

- In addition, there were several nominated "Honorary" vice-chairs of the SC, reflecting their history and contribution to the conference. They had no formal role, other than on occasion to provide a sounding board and sage advice to the SC chair.

Nevertheless, since the inception of the conference, the organisation, execution and leadership has depended on good will and voluntary participation by many nations, organisations and individuals from across the community. There was a lack of permanence in the support organisation for the conference, which meant that those on the ground had to relearn many of the lessons each year, select and use conference tools, build relationships with the local IEEE chapters, etc; continuity was not ensured. Each year a hosting nation needed to be identified and much of the burden fell on them in terms of the technical programme and local organisation. Additionally, the financial aspects of the conference had to be covered from conference fees and any contributions from the hosting nation or organisation; ICMCIS as an organisation had no permanent budget. This always made for a difficult additional burden, to manage the financial aspects and make books balance. A list of the conference venues and sponsor, NATO high ranking attendance, etc., is included as Annex F to this TER.

For 2023 a new paradigm was established for the conference. For 2023 the 'ownership' of ICMCIS was passed to the Collaboration Support Office (CSO) within the STO, with the conference organised as an STO symposium, designated as IST-200, under the Information Systems Technology (IST) Panel. The conference was held in conjunction with the Spring 2023 (51st) IST Panel Business Meeting (PBM). Administrative and financial support was provided by the CSO staff.

With this shift of ICMCIS to the CSO ownership, the conference is defined in a Technical Activity Proposal (TAP), which must be approved through the formal processes. In the TAP, the conference is defined as a Symposium, which bring with it certain requirements, such as the need for a Technical Evaluation Report.

With this change of ownership of the conference to the CSO, the organisational structure was modified slightly, to wit:

- The SC remained in place with a similar role as before;

- The Chairmanship of the SC was shared amongst two 'Team Leaders': Antoine Smallegange of the NLD and Ms Latasha Solomon of the USA. The intent is that the Deputy Chair of the IST panel would serve as one of the Co-Chairs of the SC;

- One of the Co- Chairs of the SC (Antoine Smallegange) acted as Conference Chair throughout the two days. No Vice Conference Chair was evident;

- A Core Team was established, largely consisting of a subset of members of the SC and the TPC, which provided support throughout the lead up to the conference;

- The TPC, consisting mostly of previous reviewers, augmented with some new members, was responsible for reviewing the papers. The scientific chair of the conference (Mitko Bogdanoski) was also chair of the TPC. The actual reviewing process was heavily supported by the conference chair and TER Author;

- The CSO, largely through the IST Panel Executive and Assistant, but including others, provided administrative support, financial support for the conference, funding for software tooling, etc.;

- The Host Nation remained responsible for organising local arrangements, conference venue, social events, and so on; and

- The awards committee was formalised with a set of operating instructions, which defined how the process would work.

This year the conference was sponsored by the General Mihajlo Apostolski Military Academy in Skopje, North Macedonia, and occurred on 16 and 17 of May 2023. In addition, the conference was supported by the NCIA, and the Polish NASK, their state institute for research and implementation of secure ICT networks. Finally, many others from a variety of nations and institutions have contributed time to make ICMCIS 2023 a success.

B1.1.1   Background

The International Conference on Military Communication and Information Systems (ICMCIS) is the largest scientific/technical conference in Europe on military CIS. This event was previously organized outside of formal CPoW channels, but there has been a strong relationship with the IST panel for the better part of the last decade:

B1.2   Administrative / Organisational Conclusions and Recommendations

The following major Administrative and technical conclusions and recommendations are reported here in two sections, those of general nature and dealing with issues prior to the conference and those dealing with issues during the conference.

B1.2.1   Organisation and Pre-conference

- The ICMCIS Steering Committee consists mostly of IST-panel members. This leads to a very IST centric conference attendance and scientific topic coverage.

  - **Recommendation** [A1]: Through the CSO work to ensure that other panels and groups are represented on the SC. The goal should be to have at least one SC member from each CSO panel and group as members of the SC in time for the 2024 ICMCIS;

- ICMCIS 2023 was an important dissemination and benchmark event for IST-activities, with many of the papers linked directly to the output of IST research activities. With the publication of the papers in IEEE Xplore, this provides a further opportunity to disseminate the results to a wider audience and increase their scientific value;

- The paper solicitation, review, acceptance cycle for ICMCIS 2023 was posed several challenges.

  - The call for papers was not formally issued until mid/late autumn 2022. This is very late for a conference of this nature, considering that we require full papers to be submitted, evaluated by a minimum of three peer reviewers, papers to be updated taking into account review feedback, presentations to be submitted ahead of time and so on. Because of the late CfP, the entire cadence of the paper acceptance cycle was disrupted;

  - The late CfP resulted in the deadline for paper submission being delayed several times, putting much pressure on the TPC and individual reviewers;

  - The original paper submission deadline had to be extended twice as insufficient papers were received by the original deadline or first extension dates to result in a viable conference;

  - Technology Protection processes for US attendees added an additional ~2-4 weeks to approval process which resulted in delayed submissions.

  - Many reviewers did not fill out their areas of expertise making assignment of papers to reviewers problematic. This also led to papers being assigned to reviewers that were perhaps less them expert in the topics covered in the paper. This reduces the value of the peer review and may in some cases lead to inappropriate acceptance or rejection of a paper;

  - Many reviewers in the list of TPC members, did not deliver reviews on time, did not review all assigned papers or did not review any papers at all, passing the burden on to others in the TPC;

  - Some authors who had conditionally accepted papers, had to wait very late in the whole process to hear whether their papers were accepted;

  - In some cases, US Co-authors were not approved for international conference travel given timeline of acceptance notification.

  - **Recommendation** [A2]: The call for papers (CfP) should be available at the time of the preceding year's conference so that attendees can receive a copy a full twelve months ahead of the event and have critical information available regarding the follow-on year's conference. This should happen even if all the formal steps are not completed and the CfP needs to be released clearly marked as a draft; and

  - **Recommendation** [A3]: The TPC members' list is in urgent need of review with the goal of weeding out the names of people who are no longer able to contribute appropriately. It needs to be augmented with additional experts, in line with the topics that will be chosen for 2024. Efforts should be made to encourage young scientists to participate in the TPC process.

  - **Recommendation** [A4]: Consider options to host parallel, controlled technical track in line with recommendation T5, above.

  - For 2023 the distribution of Call for Papers (CfP) was done via IST-panel members with additional dissemination being achieved through Science Connect and direct contact to the other panel chairs. Nevertheless, the conference remained IST centric.

- There existed at the end of the day three different lists of conference topics: the topics identified in the TAP, the topics identified in the CfP and the themes identified as conference tracks. It was determined that no one-to-one mapping could be made between these and so a conclusion of whether the stated aims in the TAP have been met. The actual mapping is addressed under Technical Conclusions and Recommendations, but from an administrative side we make the following recommendation:

  - **Recommendation** [A5]: Bring coherence to the list of topics so that those identified in the TAP are carried through to the CfP and onwards to the presentation tracks that are used in the conference. If the TAP is agreed on the basis of particular topics, then this should facilitate a post-event analysis of whether the agreed scope was realised. It is understood that authors cannot be forced to present at ICMCIS, so this will only be a first assessment; however, a coherent list of topics would facilitate any analysis.

- The conference tool used for submitting, reviewing, etc., of papers this year was EasyChair. EasyChair has been used for the past three years for this purpose and is certainly capable, but not perhaps perfect. The user interface is not always intuitive, the learning curve is steep, the way it considers to weight scores depending on the reviewers' expertise, and a few features one would like are not present. The plusses are that it is relatively inexpensive, the EasyChair support team is very responsive, and we now have some experience and expertise built up with the tool.

  - **Recommendation** [A6]: A small team should be established to identify and evaluate available tools and make a final recommendation for what tool should be used going forward, with a view of making it a pan-CSO tool. Options such as EasyChair, EDAS, ConfTool and others should be considered in the mix. This is urgent if it is to influence the ICMCIS 2024 cycle, as we will need it in place the tool by 3Q23. If this cannot be accomplished in the short-term then the recommendation is to stay with EasyChair for 2024.

  - **Recommendation** [A7]: EasyChair, or other agreed upon conference management tool, should be maintained by the same entity managing ICMCIS website.

- ICMCIS is an important source for new ideas (Technical Activity Proposals (TAPs) and Tech Watch Cards (TWCs)).

- The SC structure appeared to work well and should be retained.

- The Core Team was a useful addition to the organisational construct and should be retained in future. It provides the Chair with a working body to support the overall efforts.

- Fifty-nine papers were submitted to the conference in response to the call for papers. A total of 30 full papers were presented, as well as seven Posters, five keynote addresses and four industry presentations. Only the 30 papers selected for full presentation will be published in IEEE Xplore. While 59 paper submissions are adequate to proceed with a good, high-quality conference, a greater number would be beneficial. The benefits of a greater number of submitted papers would include a better coverage of the conference topics and attract a more diverse conference audience.

  - **Recommendation** [A8]: Efforts should be made to increase the number of papers submitted. A reasonable target for 2024 should be 100 submissions, building on that number in subsequent years. Options to encourage more papers submissions might include:

    - Work with the other Panels to submit papers of interest to the combined communities;

    - Utilise additional routes to market, such as other mailing lists, paid advertisements in leading magazines or websites; e.g., IEEE, Spectrum, Elsevier, IET, or other professional organisations;

    - Consider the creation of a Maritime Track to encourage papers from CMRE and nations conducting research in the Maritime domain; and

    - See also Recommendation A1;

- While the effort by NASK to host the ICMCIS web site over the past number of years is appreciated, there is an inherent delay in updating content in real-time often resulting in dated information on website for several days.

  - **Recommendation** [A9]: Have CSO take over the hosting of the web site and ensure processes are responsive.

- This year one of the Co-Chairs of the Steering Committee acted as the overall Conference Chair. In the past this role has fallen to one of the local host nation organisers, specifically the Head of the TPC.

  - **Recommendation** [A10]: The Chair of the conference role should revert to the Host Nation. The honour of this role should fall to the TPC Chair thus freeing up the SC Chair from this burden in order that they can fulfil their SC Chair mandate, undistracted.

- This year there was no Vice Chair for the Conference. In the past this role was filled by the individual from the follow-on year's Host Nation that would act as the TPC Chair and Conference Chair, providing them with an opportunity to gain experience and provide a smooth transition from one year to the next.

  - **Recommendation** [A11]: Reinstate the role of Vice Conference Chair, chosen as the follow-on year TPC Chair from the follow-on year Host Nation, with the aim that the individual shadows the Conference Chair and learns the role. This role could be combined with the SC Co-Chair role, with one Co-Chair being the Deputy IST Panel Chair and the other being the follow-on year TPC Chair.

- In a number of cases the session chairs selected were either not present or had conflicts. This caused slight delays and led to a lack of preparation by the person finally filling the role. It appeared that session chairs were not all aware that author biographies were available to them, in order to provide good introductions.

  - **Recommendation** [A12]: Session chairs should be selected and deconflicted well ahead of time. It is also recommended that a short session chair meeting be held the night before the conference starts to ensure all are still available and understand the expectations of their role.

- Regarding the TER process:

  - Requiring that a TER be prepared is a positive development as it will provide an opportunity to learn lessons and make the conference better year-on-year. This was not done in the past and so many lessons were lost and had to be re-learned;

  - One downside is that with parallel sessions being a necessity, it is not possible for a single TER Author to attend all sessions and make first-hand assessments. Hence some opportunities for feedback and collection of lessons learned may have been lost; and

  - Having the TER Author involved from the outset of the conference organisation; i.e., from about the autumn of the year before the conference, is essential so that feedback and lessons learned regarding the organisational and administrative aspects can be captured;

  - **Recommendation** [A13]: The TER Author should be identified early in the annual cycle and encouraged to attend the SC and other preparatory meetings. In these, the role of the TER Author should be to capture new lessons learned, but also to remind the group of the lessons learned in previous years.

  - Assessment of the demographics of the attendees indicated that of the approximately 122 attendees (including authors, keynote speakers and some of the supporting staff), a mere 14 were women, representing only a 11.5.%/88.5% female to male ratio.

  - **Recommendation** [A14]: Encourage more female scientists to attend the conference. Perhaps this could be accomplished through creating an additional category of award: The best paper by a female scientist award or including topics where we know there are more female scientists working.

- One hundred and eight attendees from 22 of the 31 NATO member countries were present, along with representatives from Switzerland (1), Sweden (5), Singapore (3), Morocco (1) and Ukraine (4), leading to the approximate total of 122 attendees. The precise breakdown is indicated in Annex D. The NATO nations missing from the list of attendees were: Greece, Albania, Romania, Montenegro, Croatia, Czech Republic, Latvia, Luxembourg and Iceland. It is perhaps somewhat disappointing that many Balkan countries were not represented, even though the venue was held in their neighbourhood.

  - **Recommendation** [A15]: Encourage the nations not in attendance to submit papers in the coming year to ensure that all NATO nations are represented and are benefitting from this information sharing opportunity.

  - **Recommendation** [A16]: Encourage nations in geographical proximity to the ICMCIS location to participate in greater numbers. One of the reasons that ICMCIS has changed venues on an annual basis is to encourage neighbouring countries to participate and benefit from information sharing opportunities.

- This year's conference can be seen as the start of the next stage of the journey to improve ICMCIS, as it was the first year that the leadership was exercised by the CSO and IST Panel. This change of leadership was undertaken with the expectation that it would provide certain benefits and improvements in both the technical and organisational aspects of the event. Some of the expectations are hinted at in the TAP but nowhere are they fully developed or codified. The following initial recommendations are made in this regard:

  - **Recommendation** [A17]: The expected benefits of the change of leadership should be codified and measured to understand if they are being achieved or if additional measures need to be taken or refinements to the structure need to be put in place;

  - **Recommendation** [A18]: Considering what took place this year, an assessment should be made of the support that the CSO must, should and / or could provide going forward, with an understanding of the cost & benefits that each support measure might bring. Currently the burden of ICMCIS falls heavily on the IST Panel Executive in the CSO and the Chair and particularly the Vice Chair of the IST Panel. Questions such as: "Is this model sustainable?"; "If there is a change of personnel in the CSO or the Panel, will things transition smoothly?"; "Are staffing levels in the CSO sufficient or should some short-term targeted augmentation be considered?"; etc. need to be answered; and

  - **Recommendation** [A19]: A detailed ICMCIS Handbook / Body of Knowledge should be created and maintained, updated annually, to ensure that lessons are captured, roles are defined, responsibilities are not missed, proper turn over can be accomplished when personnel change, etc. It should also codify the annual cycle of the conference, defining the business process followed and steps that need to be taken according to a timeline, so that pieces are not missed in the future and the whole process becomes repeatable.

- The publication of the papers in IEEE Xplore continues to be seen as providing value to the community and the authors. It provides a route to a wider dissemination of research results and provides some prestige to the authors, even if this is universally accepted by all nations.

  - **Recommendation** [A20]: Publication of the proceedings in IEEE Xplore should be continued in the future.

- While the TER Author only had an opportunity to sit in on a third of the paper presentations, due to the three parallel track structure of the conference, the overall impression and opinion is that the conference was of a high scientific standard and high military relevance. Many significant results were presented during the course of the conference, and perhaps more importantly, many new thought-provoking topics for further investigation were identified and new network connections were formed, boding well for continued future collaboration opportunities.

B1.3 Conference Execution

- The ICMCIS was very well attended, with approximately 120 delegates, most of whom were present for both days. The event attracted scientists and military personal from a broad set of disciplines and nations. The exact number of attendees is not known as the Industrial participants did not formally register and there were perhaps up to 10 students in attendance from the General Mihajlo Apostolski Military Academy. Additionally, there were several attendees known to the TER Author that were not included in the attendance lists provided to him.

    - **Recommendation** [A21]: All attendees should go through a registration process, even if abbreviated, so the attendance to the conference is known and badges can be properly issued and controlled for security purposes.

    - **Recommendation** [A22]: For reasons of safety, security and record keeping, process need to be in place to ensure a 100% accurate attendance list. It makes no sense screening and eliminating certain nations' citizens from attending, but not actually knowing who was in attendance on the day.

- The administrative arrangements were generally of a high standard. All coffee breaks, social events, dinners were also of an excellent quality and very much appreciated by the attendees. The venue offered many local restaurants and snack bars for lunches, which made it easy for attendees to have lunch and still be back on time for the afternoon sessions. Much positive feedback was received and credit goes to the local organisers and Host Nation.

- The conference facilities were adequate to the purpose. The room where the plenary sessions were held (Millennium) was large and the acoustics were good as were the Audio-Visual (AV) facilities. A room used for one of the separate tracks (Galeb) was far too small resulting in people either unable to attend or needing to stand. With a conference attendance of nearly 120 people, it should be anticipated that parallel tracks will attract around 40 people each, so rooms need to be sized appropriately.

    - **Recommendation** [A23]: Ensure that all rooms are adequate to the be able to host the expected number of attendees.

- The regular tracks allowed for 30 minutes per paper presentation, including questions and answers. This was seen as positive as it allowed for a fuller presentation of the paper contents and importantly more interaction during the questions and answers.

    - **Recommendation** [A24]: Attempt to keep the 30 minute per paper format. In the past shorter paper presentation times have been tried, with a negative effect both on the comprehensive presentation of research results and audience interaction opportunities.

- The papers selected for presentation were grouped into eight themes, presented as separate tracks during the conference. These roughly corresponded to the topics identified in the TAP and the CfP, albeit at an aggregated level:

    - Artificial Intelligence (AI)

    - Transmission

    - Tactical Networks

    - Quantum

    - Data and Information

    - Antenna

    - Cyber Security

    - Software Defined Radio

    This selection of conference tracks proved to be reasonable and worked well for the purposes of the conference.

- The keynotes were interspersed with the regular tracks, which kept people engaged and helped encourage them to remain for the full duration of the conference. See also Recommendation T14 above.

- The industry presentations were the subject of a separate track, which was conducted in parallel with the regular sessions. This proved to be a reasonable approach. The sessions attended by the TER Author were valuable as they revealed industrial capabilities and thus potential future partners; however, they were not scientific in nature. The papers that the TER Author attended were statements of current industrial capabilities, not new scientific results.

  - **Recommendation** [A25]: It would be useful to encourage industry to provide papers of a scientific nature. For example, industry papers dealing specifically with their approach and developments in the area of next generation satellite communication constellations, or the results from projects undertaken through DIANA might be useful and provide interesting insights that will inform the CSO community. As we know industry has been instrumental in driving many innovations in the past decades. This trend will continue, and it will be important to engage with them and understand what they are doing, but also influence them by helping them understand the specific needs of the military. ICMCIS could provide a forum for such a dialogue.

- At the outset of the conference, it is usual to cover administrative and health and safety issues, particularly emergency and security procedures. These topics were not addressed at ICMCIS 2023.

  - **Recommendation** [A26]: CSO prepare a standard briefing that can be particularised each year to ensure that these important issues are covered at the outset of the conference.

- Two prizes were awarded at the closing ceremony. The prize for the overall Best Paper went to paper 9371, *A Data Mesh Approach for Enabling Data-Centric Applications at the Tactical Edge*, by Simon Dahdal, Filippo Poltronieri, Mauro Tortonesi, Cesare Stefanelli, and Niranjan Suri. The Best paper by an Early Career Scientist (ECS) was awarded to paper 9728, *Mobility Prediction at the Tactical Edge: A handover for Centralised / Decentralised Tactical Networks*, by Merlin von Rechenberg, Johannes F. Loevenich, Philipp Zißner, Paulo H. L. Rettore, Roberto Rigolin F. Lopes and Peter Sevenich.

- The process for selection of the best paper prizes was well documented by Dr Bob Madahar, the Chair of the Best Paper Committee, ahead of the conference. The processes were assessed by the TER Author as having been stringently followed and lead to a fair result. Nevertheless, a few questions remain regarding future best paper award, particularly in regard to the ECS award:

  - ECS is currently defined as someone who has not yet achieved their 37th birthday. Many feel that this age represents a mid-career scientist and that perhaps the award should be reserved for younger people;

  - The exact contribution of an ECS to a paper that is authored by a list of contributors is sometimes difficult to ascertain, and hence it makes for a challenging comparison between ECS award candidates;

  - In certain cases, it is possible that the best ECS paper is also the best overall paper, as happened this year. In this case the best paper award was given to the paper, with the second place ECS finisher being awarded the ECS award.

  - **Recommendation** [A27]: The IST Technical Awards committee consider these three issues and generate recommendations regarding how they can be dealt with for agreement at the ICMCIS SC level.

Annex C – PRESENTATION SUMMARIES AND ABSTRACTS

This Annex provides the abstracts of the papers presented at ICMCIS as full papers or as posters. Here the papers and posters have been grouped by major 'Themes' and a summary of the major results of the papers is provided for each theme. The themes follow closely, but are not identical to, the 'Tracks' used during ICMCIS to logically group papers for presentation. The text of the full papers is available from the STO web site and IEEE Xplore.

At the conference, there were four keynote presentation, 30 full papers, seven posters and four presentations from industry. The summaries of the keynotes are presented first, followed by paper abstracts, according to their themes. The posters are included under the appropriate theme to keep similar topics together and can be identified as a prefix 'P' has been added to the paper number. Industrial papers are included as an eight theme and in this case the prefix 'I' is used to distinguish them.

C1.0   KEYNOTES

Keynote 1 – NATO Keynote – CSO Director, Mr John-Mikal Størdal

Following a very short summary of his career and background, the CSO Director emphasised the importance of the ICMCIS conference, the largest European conference on Military CIS matters. He also welcomed the non-NATO partners such as Ukraine and Singapore. He came back to this point several times, noting that ICMCIS provided and excellent opportunity for sharing of Information Systems Technology (IST) Panel results but also could be used for sharing beyond the IST Panel to a wider community. The emphasis placed during ICMCIS on encouraging the next generation of scientists was also noted and welcomed.

He discussed the 'technological edge' stressing the importance of having access to the best weapons and technology, noting that the war in Ukraine is a seismic shift. He discussed the importance of collaboration, and how the identified Emerging and Disruptive Technologies (EDTs) are a cornerstone to this and that recently the existing list has been extended to include Next Generation Communication systems.

The Director then discussed the emerging concept of Multi-Domain Operations (MDO), which aims to connect five domains of operations (Land, Sea, Air, Space and Cyber) in and amongst each of the 31 nations. He noted that this is a huge challenge but also that it is urgent given the need to fuse Space and Cyber Defence, as well as non-military players such as NGOs and civilian organisations. He also discussed the need for cultural change in NATO and the Nations to make MDO successful.

He also discussed the value of data, noting that an Economist estimated that the value of data is higher than the current value of the world's oil and gas reserves. He then discussed the need to get inside the decision loop of our adversaries by facilitating faster and higher quality decision making, and discussed the promise of quantum technologies, which he suggested can only be leveraged through cooperation.

The Director then discussed the importance of investing in Science and Technology (S&T), noting that it is more important than ever before. He noted that S&T is the cornerstone of being able to deter and defend, and discussed the opportunities that exist in sensor technology, AI and ML, which can help to leverage enormous data sets that are produced by new sensors. He emphasised that this would be a marathon, not a sprint, and how the Cooperative Programme of Work (CPOW) is an efficient model that supports these aims. He noted that CPOW is the largest S&T network in the world, bringing together the best minds to find solutions, and that it brings efficiency, with one nation (the UK) reporting a 10:1 return on their investment in the CPOW due to leveraging of other Nation's effort and expertise. The Director mentioned the Defence Innovation Accelerator for the North Atlantic (DIANA) as an important development in this space as it brings new

opportunities and new partners to the table. He discussed the need for pragmatic solutions, involving prototyping and rapid experimentation.

He concluded by emphasising again that ICMCIS is key to maintaining the technological edge, as it creates a forum for sharing and disseminating information and identifying new collaboration opportunities.

Keynote 2 – Scientific Keynote 1 – Professor Popovski

Dr Popovki's presentation covered a topic of high interest to NATO; that is, the topic of the most recently identified NATO Emerging and Disruptive Technology: Next Generation Communication Systems.

At the address, Professor Popovski discussed the evolution of 5G to 6G, and the revival of satellite connectivity. He explained that 6G will add intelligence learning, localisation and sensing to the standard communications model of 5G, which was focused on enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC) and massive Machine Type Communications (mMTC). He discussed the potential of the Internet of senses, perceptions of time, the value of information, and the convergence of satellite and terrestrial networks. He also discussed the different types of satellite orbits, such as LEO, MEO, GSO, GEO and HEO, and revolution that was happening in space due to the orders of magnitude lower costs of launches and miniaturisation of space craft. He also discussed the use of Reconfigurable Intelligent Surfaces (RIS) as reflectors to reradiate signals in desired directions, and the use of federated learning to address issues of privacy, unbalanced data sets, and massively distributed data sets. He concluded by noting the rekindled interest in satellite connectivity, and the need to rethink distributed algorithms for federated learning. He also highlighted the many new research problems that need to be addressed, such as distributed algorithm design, satellite IoT, and Edge computing with satellites.

Keynote 3 – Operational Keynote – Ukraine

Maj Yelyzaveta Boiko and First Lieutenant Dmytro Teslov of the Delta Team from the Ukraine presented an Operational Keynote regarding their Delta family of C2 tools. These tools provide Situational Awareness (SA) and Common Operational Picture (COP) functions, Ballistic Calculations, Intelligence, Secure Chat, Geographic Information Systems, a Wiki, and the ability to consume Drone feeds, videos streams, file sharing, and commercial data providers. Importantly, they discussed not only the products capability, but also their development approaches and architecture, covering aspects of People, Processes and Technology.

The Team discussed their use of Agile development methodologies to quickly adapt the DELTA tool set to new or changing operational situations and to continually enhance capabilities. This methodology embraces commercial approaches to improve speed of delivery.

The Delta Team also discussed the concepts of accessibility, reusability, and safety. The tools run in the cloud and use NATO standards, providing interoperability between sensors and weapons systems. The Delta Application has a three-stage pipeline: ISTAR, responsible for ingestion, aggregation, verification and further dissemination of data; a Common Operational Picture to provide situational awareness; and distribution of information to operators, commanders, brigades, artillery, drones, etc. Multi Domain Operations (MDO) is baked in from the outset in the thinking and design.

The Team relies on open-source software and implements a zero-trust framework. They use UKR National Digital Passports to authenticate users and have strict access control of information, by data element, hiding source information. The applications are implemented in the Cloud and rely on a Bring Your Own Device (BYOD) approach (tablet, smart phone, laptop), providing both custom APP forms of tools and web interfaces. It relies on a combination of Starlink and military and commercially available terrestrial radios for communications. Cyber security employs Mobile Device Management (MDM), a physical token (FIOD-2), EDR Endpoint Detection and Threat Response, and is regularly penetration tested (PenTest) to ensure security. Recently, the application withstood a significant Distributed Denial of Service (DDoS) attack.

In closing, the presenters extrapolated the future as a war of machines, where cyber defence would be paramount, routine work would be automated, and more sources of information would be available and included. They concluded by providing the following key insights:

- learn from the best- do not reinvent what is working;

- keep standards in the core, but be flexible;

- use as much from commercial and open source as you can;

- navigate the changes, don't follow;

- MDO first thinking;

- validate your ideas on the battlefield, ASAP;

- horizontal communications is key;

- build a network of innovators;

- lessons learned need to become lessons applied; and

- keep fighting for a better future.

The audience gave the Delta Team a standing ovation reflecting the acknowledgement of the pressure they are under, and the admiration for what they had achieved in a short time.

Questions following the Team's presentation addressed the Delta Team's experience with cyber attack, which caused them to switch from a Time-Based One-Time (TOTP) to a two-factor authentication -FIDO-2; their sharing of lessons learned in regard to standards, etc., with NATO through the MIP working Group; their significant use of open source intelligence feeds, but validation of these with other sources of intelligence; and their agile approach, which has a cadence of one release of software a week for major modules and perhaps up to three or four for smaller modules.

Keynote 4 – Scientific Keynote 2 – Professor Chris Reed

Professor Chris Reed presented a very entertaining and thought-provoking keynote based on the work undertaken by him and his team at the University of Dundee concerning Argumentation Theory.

Professor Reed covered the theoretical aspects and the problems he was trying to solve indicating that the 'holy grail' was to be able to analyse, in real-time, oral debates and extract automatically extract the argumentation. The theory involved developing and standardising a framework that could be used to capture elements of argumentation discourses in a systematic and unambiguous way facilitating further analysis.

Dr Reed stressed the importance of having a multidisciplinary team, including individuals with backgrounds in philosophy, linguistics, artificial intelligence, computer science, etc.

Dr Reed discussed several examples of where he has used the technology to support organisations such as the BBC and others to help analyse topical debates or support students in improving their argumentation skills.

One interesting aspect was that it appeared to be feasible to identify a particular individual from the specific way they engage in a dialogue. Another interesting aspect of that Dr Reed's work is that provides a potential avenue to tackle disinformation and fake news.

The presentation was well received, and the technology could certainly be of value supporting committee meetings and other consultation fora in NATO or similar organisations.

C1.1 THEME 1 – Artificial Intelligence and Machine Learning

The AI and ML theme touched on a number of interesting and military relevant topics: the ability of publicly available language models to generalize to the NATO context, the intrinsic performance of transformer models for Natural Language Processing (NLP) tasks on domain-specific text, the potential definition and application of robustness criteria for machine learning systems, a proposed disinformation analysis and tracking dashboard, a spatio-temporal memory density clustering for battle space object aggregation, a visual analytics tool for activity based intelligence, and the evaluation of metrics for autonomous decision making.

6731 – *Riccardo D'Ercole, Arvid Kok, Philip Eles, Giavid Valiyev, Michael Street,* ***Can publicly available models understand NATO language? A named entity recognition case study***

In this research we address how well publicly available language models can generalize to NATO context. Expanding on the Natural Language Processing (NLP) task of named entity recognition (NER), we test a BERT fine-tuning strategy using different combinations of pre-trained models, tuning datasets and NER problem complexity. We demonstrate how these choices have a fundamental impact on out-of-domain and in-domain task performances and demonstrate a trade-off between generalization and memorization in our NER model design.

5766 – *J. DeMarchi, R. Rijken, J. Melrose, B. Mahadar, G. Fumera, F. Roli, E. Ledda, M. Aktaş, F. Kurth, P. Baggenstoss, B. Pelzer, L. Kanestad, Evaluation* ***of Robustness Metrics for Military Machine Learning Systems***

In this paper we explore some of the potential applications of robustness criteria for machine learning (ML) systems by way of tangible "demonstrator" scenarios. In each demonstrator, ML robustness metrics are applied to real-world scenarios with military relevance, also showing how they can be used to help handle possible adversarial attacks on ML in operational context. We conclude by sketching promising future avenues of research in order to: (1) help establish useful verification methodologies to facilitate ML robustness compliance assessment; (2) support development of ML accountability mechanisms; and (3) reliably detect, repel, and mitigate adversarial attack.

1029 – *Giavid Valiyev, Philip Eles, Arvid Kok, Riccardo D'Ercole,* ***Comparison of transformer models for performance on domain specific texts: A systematic evaluation of intrinsic model performance***

This paper presents a systematic evaluation of transformer models for Natural Language Processing (NLP) tasks on domain-specific text. The objective of the study is to understand if intrinsic performance statistics can help determine the now suitable a transformer model is for a given target corpus and NLP task, where directly measuring performance is not possible because of lacking labeled data. A number of pre-trained transformer models are considered, including BERT, BART, SciBERT, RoBERTa, and XLNET which are evaluated by measuring the intrinsic performance of such models, by examining the distribution of sentence embedding vectors in the sematic hyperspace, prior to applying any downstream NLP task. We consider this intrinsic model performance for domain-specific texts (in our case on military domain texts as well as texts on which the models were originally trained) in the case when that text deviates from the domain on which the model was originally trained. The results of the study provide insights into the characteristics and intrinsic performance of different transformer models on domainspecific text. Our results can be used to inform the selection of a model for downstream NLP tasks given an input dataset. Overall, the study contributes to the understanding of the trade-offs between different transformer models for NLP tasks on domain-specific texts, and how to make informed decisions about which model to use for a specific input dataset.

6599 – *Justina Mandravickaitė, <u>Milita Songailaitė</u>, Eglė Kankevičiūtė, Anton Volčok and Tomas Krilavicius,* ***Disinformation Analysis and Tracking Dashboard***

The importance of disinformation identification and tracking in the information age is not questionable. War in Ukraine, information attacks in Baltic states, and a number of other disinformation attacks worldwide show that it is becoming a conventional tool in information space. In this paper, we present a disinformation analysis and tracking dashboard. It has 3 main components: Disinformation Analyzer, Match disinformation cases, and Model Accuracy. The first component consists of a fined-tuned RoBERTa model for classifying textual input into fake and neutral. The second component contains semantic matching functionality for checking the semantic similarity of input text to the set of known disinformation cases. The third component includes the confusion matrix and model accuracy information. All 3 components have been combined into visual analytics platform for easy inspection and exploration of potential and known disinformation cases. The majority of the work was done during TIDE Hackathon 2023 as a part of the Disinformation Analyzer Challenge.

4093 – *Sebastian Stucken, Jonathan Cawalla,* ***TM-DBSCAN: A Spatio-Temporal Memory Density Clustering for Battle Space Object Aggregation***

The aggregation of Battle Space Objects (BSOs) within a situational picture is the combination of BSOs into units, i.e., higher organizational entities. Aggregation is part of situational assessment. As has been shown by [1], aggregation can be achieved by clustering, in particular DBSCAN. In this paper, we present a significant improvement of the DBSCAN approach, namely Temporal Memory (TM) DBSCAN: the situational picture is enhanced with a temporal memory (TM) so that previous situations can be taken into account for clustering the current situational picture. Thereby, it becomes possible to "remember" previous but still valid divisions of BSOs as well as to recognize outdated BSO representations that should be ignored. We describe the TM-DBSCAN algorithm in detail and explain its effects on aggregation.

P6697 – *Valérie Lavigne, Alexandre Bergeron-Guyard, Enabling* ***Activity Based Intelligence with Visual Analytics***

ThornViz is a visual analytics tool presenting data along multiple perspectives for discovering the unexpected and performing activity based intelligence (ABI) analysis. It leverages a flexible data model along with a graph database to support ABI principles through interactive visual exploration of intelligence data including dynamic filtering and social network analysis techniques. ThornViz was applied to explore adversarial communication network data, to investigate crypto-currency transactions for suspicious financial activity, as well as to look for potential collaborations between NATO scientific activities, which demonstrated its multi-domain support.

P9624 – *Daniel Flintoft, Darminder Ghataoura,* ***Evaluation of Metrics for Autonomous Decision Making***

Reinforcement learning, a subfield of artificial intelligence, is a powerful tool for decision making, however, issues concerning reliability and consistency are of recent interest. In this work, we build on previous studies, evaluating a range of evaluation metrics in a guidance and navigation scenario to evaluate their ability to inform decisions regarding training of a model and how they can enable a detailed view of model behaviour. It was found that analysing a range of metrics in parallel which describe the actions of the model, and the dispersion of the training data can give a more informed decision on model reliability than reward alone.

C1.2 THEME 2 – Transmission and Antenna Systems

Major scientific themes found in the papers include: the development of techniques to manage self-interference and crosstalk in full-duplex communication systems, the potential of free space optical communications in military use cases, the analysis of link performance degradation from interferences in

military networks, the physical limits for in-band full duplex in frequency-hopping tactical radio systems, the potential of 5G O-RAN for military communications, sub-block turbo equalization for CPM waveforms in multipath environments, and the DOTMFLPI analysis of 5G for several military use cases. Additionally, the papers also discuss the assessment of the antenna mounting location on a military vehicle for jamming applications based on computational electromagnetics, the calibration of multi-robot coherent beamforming, and the design of high-isolation Yagi-Uda antennas for military full-duplex radios at 300 MHz.

8026 – *Matthias Tschauner, Marc Adrat, Vincent le Nir, Karel Pärlin, Taneli Riihonen, Crosstalk and Self-Interference Cancellation in Full-Duplex Communication Systems*

This paper provides insights into the ongoing research work of NATO IST-175-RTG that aims to demonstrate the benefits of full-duplex radios in military applications. Full-duplex radios in general allow to simultaneously transmit and receive RF signals in the same frequency band but require solving technical challenges that are not present in conventional half-duplex systems. Mainly this means suppressing the self-interference which is caused by the transmitted signal reaching the receiver path. This can result because of, e.g., circulator leakage, antenna mismatch, or reflections from the environment. Several techniques, both digital and analogue, have been proposed in literature to cope with such strong interference in the receiver path after the point from which the interference has reached there.

However, an additional challenge can arise in transceivers with improper internal isolation such as, e.g., low-cost software-defined radios, where the leaking, or crosstalk, takes place inside the radio. In such cases, the analogue cancellation cannot be positioned after the leakage point but must be implemented pre-emptively. This paper quantifies the crosstalk for one such commercial-off-the-self transceiver plus presents and compares solutions for managing both, the crosstalk and the self-interference either separately or jointly.

4435 – *Daniel Eames, Cheng Chen, Stefen Videv, Douglas McDonald, Harald Haas, Iain ME Butler, A Maritime Pointing and Tracking Model for Free Space Optical Communications in Military Use Cases*

Due to increasing congestion found in the electromagnetic spectrum, alternatives must be explored for future communication capabilities. Free Space Optical Communications (FSOC) has the potential to achieve secure, reliable, pervasive, and high-performance wireless connectivity. In this paper, the advantages / disadvantages of the application of FSOC in military use cases will be discussed with a review of the related research. We will provide a case study on the simulation of a camera-based pointing and tracking system deployed on an above-water platforms (Queen Elizabeth Class aircraft carrier / Archer Class patrol vessel).

9372 – *Kristoffer Hägglund, Jan Nilsson and Gunnar Eriksson, Analysis of link performance degradation from interferences in military networks*

In military units of the size of a brigade, a large number of frequency hopping radio networks are expected. The networks must be able to co-exist within a limited geographical area. The severity of the inter-network interference depends on a number of factors, such as available frequency space and the allocation strategy of the frequencies. To further examine this subject, we have studied how much frequency hopping VHF networks in a battalion are interfered by other networks in a brigade for a few different scenarios. In this study, the brigade was assumed to have access to a varying number of available frequency channels, and the information was spread over a varying number of frequency hops per packet. The brigade was assumed to consist of six battalions with 20 VHF networks each. The evaluation was performed using Monte-Carlo simulations with realistic path loss values obtained from a distance-dependent stochastic channel model. The results from this study show that in the worst case scenario, with access to only 200 available frequency channels, the degradation from the interferences becomes unacceptable in several scenarios. However, with access to 700 or more frequency channels, the inter-network interference is limited.

6865 – *Gunnar Eriksson, Erik Axell, **Physical Limits for In-Band Full Duplex in Frequency-Hopping Tactical Radio Systems***

Theoretically, in-band full duplex can double the spectral efficiency of a radio link by using the channel resources in both directions simultaneously. To achieve this, however, the suppression of self-interference must be sufficiently large. In this contribution we investigate the gain in spectral efficiency for full duplex, compared to half duplex, that can be achieved at different levels of self-interference suppression for radio links with parameters typical for tactical radio systems and WiFi systems. Furthermore, we investigate the effects of frequency hopping on the spectral efficiency of full-duplex radio links and compare this with the corresponding effects on spectral efficiency on half-duplex systems.

Numerical examples show that the coupling factor required to achieve a similar relative spectral efficiency gain is in the order of 40 dB more demanding for tactical radio systems than for WiFi systems. It is also concluded that the coupling factor required to achieve a certain spectral efficiency gain decreases with decreasing propagation loss. That is, it is easier to make use of in-band full duplex at shorter communication distances.

1084 – *Diogo C. Marque, Germano G. Capela, Matilde A. Costa and Arnaldo S. R. Oliveira, **5G O-RAN Potential for Military Communications***

Unlike previous generations of mobile communications, 5G is designed for more than smartphones. The low latency and high data rates, combined with the secure and reliable communications that a 5G system can provide, are useful for a wide variety of special purpose scenarios, including military applications. The military community has been investigating the potential of 5G and showing interest in this type of technology through various publications and demonstrations. However, the open Radio Access Network (RAN), as emerging paradigm, is still barely explored by the military scientific community. O-RAN principles and new architecture offer key opportunities and enablers for the use of 5G systems in military applications and boost the design of new use cases. This paper first presents an overview of the O-RAN paradigm and architecture, with a view of their potential for military applications. Then, a technical review of a military perspective of O-RAN use cases is provided, concluding with recommendations to accelerate technology maturation and potential adoption in the military ecosystem.

6150 – *Joseph Kellett, Alexander Hamilton, John Williams, Choong Hin Wong, **Sub-Block Turbo Equalization for CPM Waveforms in Multipath Environments***

Continuous phase modulation schemes are used in many NATO interoperability standards, these standards are typically designed to be employed in urban environments with harsh multipath effects which cause fast fading and phase-inversions, and as such poor bit error rate (BER) performance. Sub-block equalization, a modified form of turbo equalization, is proposed and shown to offer better performance in these multipath environments. These results are supported by extrinsic information transfer (EXIT) chart analysis of the respective inner and outer codes.

P9953 – *Harri Saarnisaari, Relja Djapic, Topi Tuukkanen, Warren Low, Nicolas Chuberre, Souradip Saha, **DOTMFLPI Analysis of 5G for Several Military Use Cases***

Defense forces are exploring the potential of exploitation of the fifth generation (5G) mobile cellular technology in the military domain. The extent to which 5G could be used in the military domain depends on the specific usage scenarios e.g., tactical operations, deployable or fixed headquarters (HQs). However, till present it was not yet studied how adoption of 5G is affecting doctrine, organization, training, materiel, facilities, leadership and education, personnel and interoperability (DOTMFLPI). This analysis if provided after reviewing 5G from the military point of view focusing on 5G features like non-terrestrial networks, massive multi-input multi-output antenna systems, beamforming, multiple access edge computing, slicing, and security and a few HQ use cases. The paper elaborates on the impact 5G has on each DOTMFLPI element and vice versa. The presented work is done within NATO working group IST-187.

5531 – *Radouane Karli, Mathias Becquaert, Luc Bontemps*, ***Assessment of the antenna mounting location on a military vehicle for jamming applications based on computational electromagnetics***

The placement of an antenna on the roof of a military vehicle-mounted jamming system presents many challenges. For that, further approaches are needed to study the effectiveness of placing antennas on these vehicles. Besides, due to the cost, time, and technical difficulties in measuring the suitable antenna locations on large tactical vehicles, there is a demand for methods to compute the optimal position for antennas before installation and for jamming coverage of 360o around the vehicle. In this paper, we analyze a simulation model based on an UWB (Ultra-Wideband) discone antenna placed on the roof of a MPP (Multi-Purpose Protected) military vehicle. The proposed discone antenna shows good UWB characteristics and operates in the frequency band from 0.81 GHz to 6 GHz for a VSWR below 2:1 over the whole bandwidth. It displays a good radiation pattern behavior with a good average radiation efficiency of around 71 % when mounted on a military vehicle. In addition, the radiation pattern was compared for the stand-alone antenna in free space taking as a reference and at four locations on the roof of the military vehicles, at five frequencies. The antenna at the back of the roof of the vehicle has the most optimal results, with adequate far-field behaviors for jamming applications. The results confirm the significant advantage of an UWB discone antenna that could be installed on a military vehicle-mounted jamming system platform as an alternative potential candidate to conventional antennas.

1529 – *Mitchell J. Grabner, Fikadu T. Dagefu, Jeffrey N. Twigg, Babak Azimi-Sadjadi, Brian M. Sadler*, ***Calibration of Multi-Robot Coherent Beamforming***

In this paper, we develop and evaluate a calibration procedure for multi-robot unmanned ground vehicle (UGV) beamforming arrays operating in challenging non-line-of-sight (NLOS) scenarios. The proposed approach is open-loop, unidirectional, and location agnostic. It enables a beamforming array to employ the help of an auxiliary agent to perform the calibration. Location agnosticism in the calibration is useful for on-the-fly array reconfiguration in urban environments. The uni-directional nature of the approach allows for increased covertness and operational simplicity by avoiding unsynchronized transmissions from the beamforming agents during calibration. We evaluate the proposed approach experimentally and in simulation and achieve highly accurate, repeatable, and reconfigurable robotic phased array calibration performance.

5168 – *Mikko Heino, Eetu Pöyry, Matias Turunen, and Taneli Riihonen*, ***Design of High-Isolation Yagi–Uda Antennas for Military Full-Duplex Radios at 300 MHz***

Military full-duplex radios enable multiple novel applications including simultaneous jamming and reconnaissance at the same frequency band. However, the high power levels in military radios have very demanding requirements for antenna isolation, analog RF cancellation and digital baseband processing to enable receiver operation with high dynamic range. This paper presents a proposed design of a novel dual Yagi-Uda antenna design for simultaneous jamming and reconnaissance with simulated isolation level of over 80 dB, 60 dB and 50 dB for bandwidths of 1 MHz, 5 MHz and 15 MHz, respectively, targeting the 300 MHz center frequency within the NATO band I. The high isolation is obtained by placing a decoupling element between two closely placed collinear Yagi-Uda antennas improving the isolation over 50 dB. The interception performance and jamming effectiveness of the whole transceiver system are studied with and without the decoupling element leading to significant improvement in interception range and increase in maximum jamming power.

P7467 – *Fabian Schmied, Jan Lewandowsky, Jörg Schöbel*, ***Practical Parameter Tuning of RF Jammers by Optimization of Expensive Black-box Functions***

In the areas of drone countermeasures, protection of critical infrastructure, and detention facility security, jamming of radio frequency communication systems is seeing increasing importance. Selecting optimized

radio signals for jamming a specific target is associated with considerable efforts, as high jamming efficiency is required. This process can be performed experimentally by continuous combination of different tuning parameters describing the corresponding jamming signal. The signal is emitted and assessed by its jamming impact on the radio link. With the amount of different parameter combinations increasing, the number of required measurements grows exponentially and so does the time investment. To approach this task, we model the search for an optimized jamming signal as an expensive black-box optimization problem. As the number of measurements is required to be minimized while satisfying real-world constraints arising from the practical context, feasible algorithms have to be found in order to solve this optimization problem. For this, we present a multidimensional iterative grid search algorithm with superior features compared to manual Human-in-the-Loop approaches in the fields of unpredictable measurements and premature termination.

C1.3   THEME 3 – Tactical Networks

The papers highlight the military significance of the technical contributions, stressing the importance of improved data sharing and processing capabilities in disadvantaged networks at the tactical edge of coalition operations, presenting a system architecture for federated and adaptive clouds that can be deployed in such networks. The major scientific and military themes found in these papers include: Combat ICT systems and their use of communication resources for more effective military operations; Distributed information exchange and policy routing across a mixture of military and civilian carriers; Adaptive user-facing services and cross-layer optimization to react and adapt to underlying network changes; Mobility prediction methodology applied in a handover mechanism to minimize packet loss and maximize time connected to centralized control; Limitations in optimizing the routing protocol in ad hoc mobile networks; Federated and adaptive clouds for disadvantaged tactical networks to enable improved data sharing and processing capabilities between mission coalition partners.

7358 – *Frank T. Johnsen, Mariann Hauge, Lars Landmark, Emil P. Andersen, Terje M. Mjelde, Jostein Sander, Martin Rytir,* ***Adaptive Networking at the Tactical Edge***

Combat ICT systems are continually being improved. More efficient use of communication resources may lead to more effective military operations. In this paper, we look at a combination of technologies that enable distributed information exchange, and we have demonstrated this using a distributed command post scenario. We have built a software demonstration leveraging off-the-shelf hardware, showcasing how we can realize policy routing across a mixture of military and civilian carriers. Further, we have deployed adaptive user-facing services, that through cross-layer optimization can react and adapt to underlying network changes. Our demonstration has shown that we can sustain adaptable service quality across frequent network changes, even including a mixture of stationary and mobile command post nodes.

9728 – *Merlin von Rechenberg, Johannes Loevenich, Philipp Zißner, Paulo Rettore, Roberto Rigolin F. Lopes and Peter Sevenich,* ***Mobility Prediction at the Tactical Edge: A Handover for Centralized/Decentralized Networks***

This paper presents a mobility prediction methodology applied in a handover mechanism that combines the strengths of centralized and decentralized network control to achieve performance and resilience in tactical networks. Our approach leverages mobility prediction to decide when to switch between centralized and decentralized network control to minimize packet loss from live user data flows and maximize the time connected to centralized control. We argue that centralized control enables software-defined networks (SDN) to manage/control network policies.

The mobility prediction methodology receives mobility trace files as input, extracts additional mobility features, and trains a Recurrent Neural Network (RNN) model to predict the system states representing the network link quality. We evaluate the prediction using two mobility models: Gauss-Markov and Manhattan-Grid. For the Gauss-Markov model, our approach achieves 44% accuracy for predicting network states 60

seconds into the future and up to 72% accuracy while predicting only 5 seconds into the future. For the Manhattan-Grid mobility model, our approach achieves higher accuracy of 67% for predicting network states 60 seconds into the future and up to 82% for predicting only 5 seconds into the future. Finally, we compared the proposed handover mechanism prediction-based with our previous RSSI-based mechanism. The results show that the prediction-based mechanism maximizes the time connected to centralized control by 56% and reduces packet loss by 1.24%.

P0900 – *Rafał Brys, Krzysztof Kosmowski, Marek Suchański,* ***Limitations in optimizing the routing protocol in ad hoc mobile networks***

The margin between real ability of connection among mobile nodes and actuality of knowledge about current topology at routing level is identified. The connection probability is considered and determined for the routing as well as physical layer level. The difference between them indicates that the routing protocols not fully use the network abilities what is confirmed by the results of simulation tests presented in the paper. The results for the modified version of the routing protocol with increased efficiency are also presented. Nonetheless there is a still a space for optimization to improve protocols efficiency measured by e.g., the packet delivery ratio (PDR).

P2223 – *Mattia Fogli, Thomas Kudla, Geert Pingen, Susan Watson, Harrie Bastiaansen, Pablo Sanchez, Niranjan Suri,* ***A Coalition Perspective on Federated and Adaptive Clouds for Disadvantaged Tactical Networks***

Military missions typically involve joint coalition operations. Disadvantaged tactical networks in which they operate often (still) suffer from limited bandwidth, intermittent connectivity, variable latency, and dynamic topology. Performance assessments have shown that state-of-the-art and common off-the-shelf civilian cloud technology can be deployed in such disadvantaged tactical networks to provide federated and adaptive cloud capabilities, enabling improved data sharing and processing capabilities between mission coalition partners. The NATO IST-193 RTG on Edge Computing at the Tactical Edge extends upon these previous performance results by addressing the system architecture challenges of distributing data and processing tasks amongst mission partners by means of federated and adaptive clouds in such disadvantaged tactical networks.

C1.4   THEME 4 – Quantum Technologies

The major scientific themes found in these two articles are the potential of quantum computing technology for military operations, the development of new cryptographic mechanisms to protect against the threat of quantum computers, and the implementation of a quantum-safe digital signature protocol in a simulated environment. The articles also discuss the applicability of quantum digital signatures in multi-domain operations and the use of the protocol to confirm orders along the command chain.

4494 – *Joanna Sliwa, Konrad Wrona,* ***Quantum computing application opportunities in military scenarios***

Quantum Information Science (QIS) is potentially a game changing technology for future military operational environment. Being significantly dependent on the capabilities of current quantum computers, it is still very immature, however evolving rapidly, and increasing the technical and knowledge potential of industrial and state actor players that invest in it. Investing in this technology can lead the NATO Alliance to gain quantum superiority and outperform its adversaries in a technological development in diverse military domains. This article presents possible applications of QIS in military domain in the form of use cases. They were formulated after analysis of today's capabilities of quantum computing technology together with prospects for the future of the quantum information domain. The article is summarized with initial recommendations for early adoption of this technology.

6936 – *Marta Irene Garcıa Cid, Daniel Gomez Aguado, Laura Ortiz Martın, Vincente Martin Ayuso, Simulated multiparty quantum digital signature in cyberspace operations*

Research on new cryptographic mechanisms to protect against the threat of quantum computers has attracted great interest, especially due to the impact that these new technologies will have on the security of cyber-operations. After the widely tested and implemented Quantum Key Distribution (QKD) protocol for the generation of symmetric encryption keys, other protocols are being explored, such as Quantum Digital Signatures (QDS). Their classic analogues based on asymmetric cryptography will be vulnerable to Shor's quantum algorithm. Given the applicability that QDS could have in multi-domain operations, in this work we have analyzed and implemented a quantum-safe QDS protocol in a simulated environment provided with real QKD-generated keys. First, we recreated a basic three-user scenario composed of one signer and two verifiers, and later generalized by increasing the number of users by simulating a scheme with one signer and multiple verifiers. Our simulation also allows one participating user to be malicious, thus playing with the number of attack vectors and the breaking points of the forwarding chain. In addition, a use case is presented in which the QDS protocol is performed to confirm orders along the command chain, demonstrating its applicability.

C1.5   THEME 5 – Data and Information

The major scientific themes found in the papers are the use of tactical edge networks for adaptive information dissemination, data-centric consultation, command and control, data mesh approaches for enabling data-centric applications at the tactical edge, exposing military sensor data using spatiotemporal asset catalogues, and non-line-of-sight ranging via ultraviolet signals. These themes focus on the use of data-driven approaches to improve situational awareness and decision-making in military operations, as well as the development of technologies to enable data-centric applications in challenging environments.

2355 – *Niranjan Suri, Lorenzo Campioni, Edoardo di Caro, Maggie Breedy, Alessandro Morelli, Roberto Fronteddu, Mauro Tortonesi, Adaptive Information Dissemination over Tactical Edge Networks*

Tactical edge networks are characterized by continuously changing link quality and topologies. Given the absence of pre-deployed infrastructure, MANET networks are often deployed at the tactical edge. Depending on factors such as location, mobility, terrain, and adversarial activity, the network may experience varying rates of churn as well as partitioning. Hence, it is typically difficult to pre-configure and optimize any network protocol to perform well across the spectrum of conditions that may occur during operations. Instead, protocols need to be able to observe the network conditions and adapt their behavior on a continuous basis to provide the best possible performance under varying circumstances. This paper focuses on Information Dissemination over tactical edge networks and in particular uses the Anglova scenario for experimental evaluation of an initial framework for network adaptation.

3323 – *Peter J. Lenk, Some Thoughts Regarding Data-Centric Consultation, Command and Control*

Building on the advances that have been made in data analytics and machine learning, there is a push to achieve data centricity; that is, to move away from the application centric (stove piped) mind-set that has dominated our thinking and solutions for decades, to a situation where we put data at the centre of our Consultation, Command and Control (C3). This offers the possibility for users to embrace data driven decision making, with the aim of facilitating more accurate and more timely decisions. On top of this, at least in the commercial world, we are seeing a shift to a more distributed approach where data exploitation is carried out 'in the business' rather than by dedicated specialist central teams, thus empowering those closest to the problem to mine data to build situational awareness, courses of actions and reach decisions relevant to their part of the business.

This current paper examines how some of the advances in the commercial world, particularly in the area of composable, self-service application delivery, can be applied to the situation of military command and control applications, providing a first answer to the questions of how might Data-Centric C3 (DCC3) differ from today's norms across the people, organisation, technology, data and funding dimensions. It argues that the data layer is the 'special sauce' that provides seamless integration and enables Multi-Domain Operations. The paper acknowledges that this will represent a radical shift in how we do things, what skills we will require, etc. While it may be possible to evolve our current systems to the new paradigm, procurement process, funding mechanisms and such will require revolutionary approaches.

9371 – Simon Dahdal, Filippo Poltronieri, Mauro Tortonesi, Cesare Stefanelli, Niranjan Suri, *A Data Mesh Approach for Enabling Data-Centric Applications at the Tactical Edge*

In modern warfare, the ability to effectively manage, share, and analyze large volumes of data in real-time is critical for military operations at the tactical edge. The use of machine learning models and data analysis services are essential for making informed decisions, predicting potential threats, and adapting to changes on the battlefield. However, operating at the tactical edge requires addressing the challenges of Denied, Degraded, Intermittent, and Limited (DDIL) networks, which are particularly challenging when it comes to data analytics, as moving data becomes a challenge and computational resources may be limited. Additionally, implementing such a system presents other challenges such as ensuring the security, trustworthiness, integrity, and privacy of data in motion and at rest. The vast amounts of data generated in these environments require a shareable and scalable solution. This requires a system that is designed to operate in an unpredictable and changing environment while still ensuring the availability and reliability of the data. To address these challenges, we propose a middleware architecture based on a Data Mesh approach, which is designed to adapt to the demands of modern tactical networks by providing a secure and efficient data-centric storage solution for (big) data. Our proposed middleware is based on a distributed domain driven approach to serve "data as a product", facilitating data management and analysis, and providing a flexible and robust solution for developing data-driven services.

8153 – Simen Ellingsen Rustad, Bjørn Jervell Hansen, Martin Gjesdal Bjørndal, Torgar Haugen, *Exposing military sensor data using SpatioTemoral Asset Catalog (STAC)*

Providing relevant sensor data for military decision makers to build and maintain their situational awareness is a persistent problem, preventing proper utilisation of collected sensor data. In this paper, we propose to mitigate this by using a data lake solution controlled by a data catalog modelling its metadata according to SpatioTemporal Asset Catalog (STAC), a specification from the satellite imagery community. The feasibility of this setup is illustrated by a military maritime use case backed by an experimental sensor data infrastructure.

5517 – C.H. Arslan, F.T. Dagefu, J.N. Twigg, T.J. Moore, *Non-Line-Of-Sight Ranging via Ultraviolet Signals*

Ranging between military assets is particularly challenging in complex non-line-of-sight (NLOS) environments where adversaries may contest access to traditional localization technologies. Recent research shows that it is possible to use technology for Ultraviolet C-band (UV-C) communication for ranging as well. Based on the channel model for non-line-of-sight UV-C links, we formulate a calibration-free ranging approach that requires no prior knowledge of the orientations of the transmitter (Tx) and receiver (Rx). Detailed sensitivity analysis of the proposed NLOS ranging approach is performed through Monte Carlo simulations, taking into account key parameters including background and shot noise, photon sampling time, spacing between spatial samples, as well as steering angle errors. Based on this analysis, we present an approach for range estimation in complex GPS-denied NLOS scenarios that utilize UV-C links.

P7845 – *Marek Malowidzki, Magdalena Kozak, Przemysław Bereziński, Rafał Piotrowski*, **Integrated Solutions for NATO Forward Medical Evacuation: Experiences and Insights**

The term "medical evacuation" means accelerated transport of casualties from point of injury, through several levels of Medical Treatment Facilities, to the country of residence. "Forward evacuation" denotes the first and most critical step, i.e, the delivery of wounded to a field hospital.

In order to enable medical evacuation in a coalition environment, its particular areas, including messages, processes and architecture, are standardized by NATO. Also, a number of solutions supporting medical evacuation are also emerging, including a reference implementation by NATO and various systems developed by individual countries. It seems, however, that the literature on technical aspects of these solutions is scarce. Our goal is to at least partially fill this gap and discuss the requirements and challenges related to the implementation of integrated systems supporting (forward) medical evacuation. Our observations and requirements are drawn from both development work on MEDICS project and experience from Poland's missions in Iraq and Afghanistan.

C1.6   THEME 6 – Cyber and Security

The major scientific themes found in these papers are the development of new Visual Analytics systems for the detection of Advanced Persistent Threats (APT), the use of Multi-Agent System for Advanced Persistent Threat Detection (MASFAD) framework and the combination of highly-detailed and dynamic visualization techniques to define sophisticated cyber threats. Additionally, the papers discuss the use of virtual laboratories for experiments with cyber security functions in coalition networks, the implementation of security function virtualization to support/speedup network topology changes, the deployment of two chains of virtualized cybersecurity functions at lower and higher protocol layers, and the development of autonomous cyber defence capabilities for Protected Core Networking (PCN).

1865 – *Georgi Nikolov, Wim Mees*, **Detection of previously unknown Advanced Persistent Threats through Visual Analytics with the MASFAD framework**

With the rapid evolution of the Internet and the prevalence of sophisticated adversarial cyber threats, it has become apparent that an equally rapid development of new Situation Awareness techniques is needed. The vast amount of data produced everyday by Intrusion Detection Systems, Firewalls, Honeypots and other systems can quickly become insurmountable to analyze by the domain experts. To enhance the human – machine interaction, new Visual Analytics systems need to be implemented and tested, bridging the gap between the detection of possible malicious activity, identifying it and taking the necessary measures to stop its propagation. The detection of previously unknown, highly sophisticated Advanced Persistent Threats (APT) adds a higher degree of complexity to this task.

In this paper, we discuss the principles inherent to Visual Analytics and propose a new technique for the detection of APT attacks through the use of anomaly and behavior-based analysis. Our ultimate goal is to define sophisticated cyber threats by their defining characteristics and combining those to construct a pattern of behavior, which can be presented in visual form to be explored and analyzed. This can be achieved through the use of our Multi-Agent System for Advanced Persistent Threat Detection (MASFAD) framework and the combination of highly-detailed and dynamic visualization techniques.

5568 – *Roberto Rigolin F. Lopes, Johannes F. Loevenich, Konrad Wrona, Paulo H. L. Rettore, Jerry Falkcrona, Joseph Mathews, Nils Nordbotten, Bogdan Vasilache, Thorsten Lampe, Olwen L. Worthington, and Juha Röning*, **Accelerating NATO Transformation with SnTEE: Experiments with Network Security Function Virtualization in Coalition Networks**

This paper introduces a virtual laboratory for experiments with cyber security functions in coalition networks. The motivation comes from the NATO Allied Command Transformation (ACT) initiative on Science and Technology Experimentation Environment (SnTEE), which supports the transfer of scientific and technical activities carried out by the NATO Science and Technology Organization (STO) research task groups towards NATO operations. The goal of the experiments reported in this paper is to emulate a network topology inspired by Protected Core Networking (PCN), which defines two interfaces. One interface between two protected core segments, from different nations, and another interface between a protected core segment and a colored cloud within a particular nation. We start with the hypothesis that security function virtualization can support/speedup network topology changes when links, using these two interfaces, are added/removed. We define our experimental setup as Infrastructure as Code (IaC) and introduce experiments that emulate topology changes. We also sketch a solution for the deployment of two chains of virtualized cybersecurity functions at lower protocol layers (physical and IP) and at higher protocol layers (transport and application). This paper also lists future experiments for the NATO SnTEE lab, namely risk-aware routing, cross-layer enforcement of policies, information exchange functions and federate monitoring and detection.

6233 – *Alexander Velazquez, Joseph T. Mathews, Roberto Rigolin F. Lopes, Tracy Braun, Frederica Free-Nelson*, **Toward autonomous cyber defense for protected core networking**

In coalition military operations, secure and effective information sharing is vital to the success of the mission. Protected Core Networking (PCN) provides a way for allied nations to securely interconnect their networks to facilitate the sharing of data. PCN, and military networks in general, face unique security challenges. Heterogeneous links and devices are deployed in hostile environments, while motivated adversaries launch cyberattacks at ever-increasing pace, volume, and sophistication. Humans cannot defend these systems and networks, not only because the volume of cyber events is too great, but also because there are not enough cyber defenders situated at the tactical edge. Thus, autonomous, machine-speed cyber defense capabilities are needed to protect mission-critical information systems from cyberattacks and system failures. This paper discusses the motivation for adding autonomous cyber defense capabilities to PCN and outlines a path toward implementing these capabilities. We propose to leverage existing reference architectures, frameworks, and enabling technologies, in order to adapt autonomous cyber defense concepts to the PCN context. We highlight expected challenges of implementing autonomous cyber defense agents for PCN, including: defining the state space and action space that will be necessary for monitoring and for generating recovery plans; implementing a suite of models, sensors, actuators, and agents specific to the PCN context; and designing metrics and experiments to measure the efficacy of such a system.

C1.7 THEME 7 – Software Defined Radio

The major scientific themes found in the papers are the development of interoperable waveforms for software defined radios (SDRs) to enable coalition forces to exchange tactical and mission critical data on the battlefield, the evaluation and optimization of physical layer waveform implementations for SDRs based on over-the-air measurements in mobile scenarios, the implementation of a low complexity generic receiver for narrowband and wideband HF, the use of game-theoretic approaches to attack planning and controller placement in software defined networks (SDN), and the coordination of the SDN and TDMA planes in software-defined tactical MANETs with adaptive coding and modulation. All of these themes are of military significance, as they are aimed at improving the communication capabilities of military forces.

6452 – *Jan Lewandowsky, Moritz Brück, Marc Adrat, Stephan Haverland, Florian Wörner, Roland Kowald, Exploiting Recorded Over-the-Air Transmissions to Evaluate and Optimize Military SDR Waveforms*

Interoperable waveforms for software defined radios (SDRs) shall enable coalition forces to exchange tactical and mission critical data on the battlefield. Typical use cases include, e.g., voice transmission and blue force tracking. The physical layer performance of a waveform crucially depends on the applied receiver algorithms. Available physical layer communication standards, however, only specify the signal generation of the transmitter. The receiver design is left entirely up to the implementer. This makes evaluating the physical layer's end-to-end performance only based on the waveform specification very challenging. Therefore, fielding waveforms clearly requires proof of the end-to-end functionalities with practical receiver implementations. In this paper, we present and discuss an approach to analyzing and improving the performances of physical layer waveform implementations for SDRs. Our proposed method is based on over-the-air measurements in mobile scenarios. We use the NATO Narrowband Waveform (NBWF) Edition 1 according to STANAG 5630 as an example to prove our concept. For this waveform, we present practical results for different scenarios and analyze the effects of various receiver configurations. To the best of our knowledge, our results are the first to be reported on the end-to-end functionality of the NATO NBWF's physical layer from practical over-the-air tests in the VHF band.

2348 – *Vincent Le Nir, Mathias Becquaert,* **GPP-SDR Implementation of a Low Complexity Generic Receiver for Narrowband and Wideband HF**

HF remains an essential military operational technology for BLOS communications when SATCOM is not available. 2G and 3G HF standards have been developed for 3 kHz narrowband channels. The latest wideband 4G HF standards enable higher data rates by increasing the bandwidth available for transmission. The two main solutions aggregate either contiguous or non-contiguous 3 kHz narrowband channels up to 24/48 kHz. This paper describes a low complexity generic receiver with channel estimation, time and frequency synchronization for 2G, 3G, 4G and HF-XL standards and a performance evaluation in terms of BER or PDR vs SNR on narrowband and wideband HF channel models. The narrowband and wideband HF standards have been implemented on a GPP-based SDR platform with open-source libraries and run in real-time.

4704 – *Konstanty Junosza-Szaniawski, Dariusz Nogalski,* **Game-theoretic approach to attack planning and controller placement in software defined networks (SDN)**

The paper addresses game-theoretic approach to controller placement and targeted attack planning problem. The two models are presented. First model, the attacker's point of view, allows for efficient attack planning using mixed strategies, with the aim to maximize damage in the network (minimize expected availability measure). Second model, the operator's point of view, allows for efficient controller placement using mixed strategies, with the aim to maximize expected availability measure, and to defend against mixed-strategy attacks. The assumption is that attacks and placements occur in multiple rounds in the form of a game. Within Software Defined Network such game is technically possible to be conducted with use of network programmability, since the controllers may be relocated. The two mixed-strategy models were implemented and tested using linear programming solvers and compared to the min-max and max-min models (single best strategy), respectively.

4353 – *Yiannis Papageorgiou, Johannes F. Loevenich, Merkouris Karaliopoulos, Paulo H. L. Rettore, Roberto Rigolin F. Lopes, Iordanis Koutsopoulos,* **Coordinating the SDN and TDMA planes in software-defined tactical MANETs with adaptive coding and modulation**

We consider a tactical mobile ad hoc network (MANET) enhanced with software defined networking (SDN) functionality. The radio transmissions of the network links are scheduled in time division multiple access (TDMA) mode and are subject to adaptive modulation and coding (AMC) to cope with the dynamic variations of the MANET links' quality. A challenge in such networks is how to satisfy the quality of service (QoS) requirements of the data traffic generated by end users while ensuring the responsiveness of the

SDN-plane control traffic to the MANET topology changes. In this paper, we respond to this challenge by jointly determining the location of the SDN controller and the schedule of link transmissions in the MANET. Expanding prior work, we model in more detail the quality variations of the tactical MANET links and how these determine the transmission modes over each link and the slot allocation process. Starting point for this model can be any node mobility model.

C1.8   THEME 8 – Industry

I001 – *Radmila Grambozova, Luka Jovicik,* **GIS DATA**

Not attended by TER Author

I002 – *Dragan Muskinja, Ivan Pepesh,* **Netra Ltd.: critical communications, networking & security**

Not attended by TER Author

I003 – *Elena Nestorovska, Salai Arif,* **ATS Group: high-quality composite ballistic products, and production of small-calibre ammunition**

The ATS Group produce ballistic products (vests, helmets, plates) and also small arms ammunition. Although the topic was not immediately relevant to the IST Panel, the presentation nevertheless generated interest as Nations are feeling supplies of these products getting tight due to their support to the UKR. ATS Group emphasised that their production capacity is being scaled up rapidly.

I004 – *Dragos Kalin,* **Kernel-group: infrastructure, datacentres, networking, virtualization, security, unified communication, wireless mobility**

The Kernel Group, a Romanian based company with a footprint in North Macedonia, who focus on digital transformation and cyber security made a comprehensive presentation regarding the nature of the cyber defence problems and their expertise in the area. Clearly, they have deep domain expertise in the area of cyber that could be leveraged by NATO or Nations in the future.

Annex D – ANALYSES

D1.0   TECHNICAL SCOPE ANALYSIS

The Technical Activity Proposal (TAP) identified the following topics for the scope of ICMCIS 2023:

- Information and Cognitive Warfare
- Signalling and Quality of Service (QoS) provisioning
- Big Data Analytics and Artificial Intelligence for Defence Applications
- Visualization technologies (3D, augmented, virtual, extended reality)
- Information and Knowledge Management
- Information and Data Fusion
- Cyber Defence and Trust Management
- Data mining and cloud computing
- Quantum Computing and Programming Languages
- Free Space Optical Communication
- Trusted Collaboration and Information Sharing
- Cognitive radio and cognitive networking
- Survivable Communication Networks
- Autonomy in Communication Networks
- Wireless Communication and Sensor Networks
- Electronic Warfare Technologies for Comms
- Electromagnetic Compatibility
- EM Spectrum Management and Sharing
- Localization and Detection Technologies
- System Architecture
- Modelling and Simulation of Information Infrastructures
- C3 Test beds and Demonstrations
- Community of Interest Services
- Core & Communication Services

The Call for Papers identified the following topics for ICMCIS 2023:

- AI for Military Decision Support and Autonomous Systems
- Big Data Analytics and Visualization
- Robotic Process Automation
- Scarce Data
- Quantum Computing and Algorithms

- VR/AR/XR/Tele-existence/Real Avatars

- Data-Centric Architecture/Security

- Distributed Resilient Infrastructure (Tactical cloud; edge computing, heterogeneous MANET; SDN/NFE for tactical networks, cognitive radio, cognitive and next generation networks)

- Internet of Military Things

- Counter/adversarial-AI and AI for Cyber

- Homomorphic Encryption

- Quantum-Safe Cryptography

- Trust Architectures/Digital Trust

- ICT Supply Chain Security (Devices and materials)

- EM Spectrum Management & Sharing

- C4I test beds, Modelling and Simulation of Information Infrastructures

- Ethical, Legal, Societal and Environmental Aspects of Technology Design/Human Machine Teaming

The papers selected for presentation were grouped into eight themes, presented as separate tracks during the conference. These were:

- Artificial Intelligence (AI)

- Transmission

- Tactical Networks

- Quantum

- Data and Information

- Antenna

- Cyber Security

- Software Defined Radio

In addition, an Industry Track was presented, covering the following topics:

- GIS DATA

- Critical communications, networking & security

- High-quality composite ballistic products, and production of small-calibre ammunition

- Infrastructure, data centres, networking, virtualization, security, unified communication, wireless mobility

The keynotes addressed issues of both scientific and operational interest to the conference:

- NATO STO and Priorities

- Technical imperatives regarding the situation in Ukraine;

- Next Generation Communication Systems

- Argumentation Theory and Application

In order to understand how well the conference addressed the topics identified in the TAP, a mapping was made between the three lists of topics identified above: TAP, CfP and ICMCIS Agenda. This exercise revealed that there did not exist a one-to-one mapping between the TAP, CfP and conference tracks. There exist overlaps between topics in some cases, but also some concepts identified in one list are not reflected in other lists. This makes it challenging to understand whether the topics identified in the TAP have in fact been covered, and if so, to what degree. A condensed mapping is presented in Figure 1 below, ordered by CfP topic. Four papers did not fit into the CfP categories and so these are added in purple, based on the TAP categories.

AI for Military Decision Support and Autonomous Systems	Big Data Analytics and Visualization	Robotic Process Automation	Scarce Data	Quantum Computing and Algorithms	VR/AR/XR/Tele-existence/Real Avatars	Data-Centric Architecture/Security	Distributed Resilient Infrastructure (Tactical cloud; edge computing, heterogeneous MANET; SDN/NFE for tactical networks, cognitive radio, cognitive and next generation networks)	Internet of Military Things
5	1			1		5	15	

Counter/adversarial-AI and AI for Cyber	Homomorphic Encryption	Quantum-Safe Cryptography	Trust Architectures/Digital Trust	ICT Supply Chain Security (Devices and materials)	EM Spectrum Management & Sharing	C4I test beds, Modelling and Simulation of Information Infrastructures	Ethical, Legal, Societal and Environmental Aspects of Technology Design/Human Machine Teaming	COI Services	Electronic Warfare	Information and Cognitive Warfare
		1	3		2			1	2	1

Figure 1: Paper numbers by topic.

The following observations are made regarding the overall mapping of papers to topics:

- The bulk of the papers (14 papers + 3 posters) fall into the traditional communication areas, including Software Defined Radio (4 papers), Tactical Networking (3 papers + 1 poster), Antennae (2 papers) and Transmission (5 papers + 2 posters). An additional two papers addressed antenna systems.

- Pure Cyber Security papers were perhaps too scarce with only four in evidence, 3 regarding conventional Cyber Security and one as an application of Quantum techniques.

- AI and Big Data were well represented with 4 papers and 2 posters, and also were part of other papers, as an application to other topics.

- Architectural issues as well as data-centricity were addressed in five papers, with two addressing directly issues of data-centricity.

- Quantum topics were addressed in two papers, one already mentioned in the context of Cyber Defence, and the other as a more general overview of Quantum Computing / Information Services.

- Information and Cognitive Warfare attracted one paper, while Electronic Warfare attracted one paper and one poster. Community of Interest Services attracted a lone poster paper.

While efforts have been made over the last several years to diversify the conference away from too heavy a focus on the traditional communication topics, the evidence is that these topics still garner the bulk of the accepted papers.

D1.1 Attendance Demographics Analyses

108 attendees from 22 of the 31 NATO member countries were present, along with representatives from Switzerland (1), Sweden (5), Singapore (3), Morocco (1) and Ukraine (4). The precise breakdown is indicated in Table 1 below[1].

Table 1: Breakdown of attendance by nationality.

Nationality	Count of Attendees
'BEL'	2
'BGR'	1
'CAN'	1
'CHE'	1
'DEU'	11
'DNK'	1
'ESP'	3
'EST'	1
'FIN'	3
'FRA'	5
'GBR'	7
'HUN'	1
'ITA'	4
'LTU'	2
'MAR'	1
'MKD'	21
'NLD'	6
'NOR'	2
'POL'	15
'PRT'	3
'SGP'	3
'SVK'	1
'SVN'	1
'SWE'	5
'TUR'	2
'UKR'	4
'USA'	7
'NATO'	8
Grand Total	**122**

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[1] The numbers are based on registration records, plus the attendance of known industry representatives, and an estimate that approximately 10 students from the North Macedonian Military Academy were in attendance. It was clear to the TER Author that some attendees had slipped through the cracks as people known to him were not in the registration lists provided.

The NATO nations missing from the list of attendees were: Greece, Albania, Romania, Montenegro, Croatia, Czech Republic, Latvia, Luxembourg and Iceland.

The gender breakdown of attendees was as indicated in Table 2:

Table 2: Gender balance of attendees.

Male/Female	NATO	Non-NATO	Total
F	13	2	15
M	95	12	107
Total	108	14	122

Sadly, the gender balance is heavily biased towards male attendees, with males representing about 88.5% of those present and only females 11.5%.

In terms of affiliations of attendees, the following were inferred, based on the stated attendee organisations recorded at time of registration. In the case of MoD, the stated numbers include both people from MoDs and national military units. In the case of NATO attendees, these included people from CSO, NATO HQ C3S and NCIA.

Table 3: Attendee affiliations.

Affiliation	Number
Academia	13
Government Lab	36
Industry	22
Military Academia	18
MoD	23
NATO	10
Grand Total	122

D1.2   Post Conference Questionnaires Analyses

For the first time a questionnaire was provided to garner feedback from participants (authors and attendees). A series of questions were asked to provide feedback on the administrative arrangements, the overall conference technical content as well as addressing specific feedback from the author's perspective.

D1.2.1   Summary of Feedback

Administrative

The attendees were very happy with the administrative arrangements, the accommodations, the social functions and the other local arrangements. They felt that the information provided through the information package, email and the portal was sufficient.

Some commented that not all conference rooms were adequate for the purpose, being too small and lacking pointing devices that worked with the LCD panels that were provided.

About half the respondents discovered ICMCIS through means other than the IST Panel, which is reassuring that the message is getting out and the conference is being discovered and attended.

Respondents pointed out that the venue, the hotel, the organisation were all good, but that the registration process could have been clearer.

Technical

Most respondents reported that they found the conference valuable, that it provided good coverage of military CIS issues and that they would think about coming again in the future.

Respondents felt that the conference might also include or emphasise the topics of:

- satellite communication systems,
- information fusion,
- AI robustness, explainability and robustness,
- Command and Control,
- data centricity, and
- and crypto.

One respondent suggested that project pitches might be included, presumably as a way of gauging interest in topic areas, while another suggested that the conference should be more focussed and cover fewer topics.

Authors

The authors who responded to the survey felt that, overall, the paper submission and review process worked well, they were very happy with the feedback provided by the reviewers and were satisfied with EasyChair as a tool. However, some criticism of the discrepancies between templates provided and CfP and online material were troublesome. There was also some concern expressed that notifications were rather late in some cases. Most authors that responded felt that publication in IEEE Xplore was important to them.

D1.2.2   Detailed Feedback

Only 17 responses were received from a total of some 122 attendees, representing only a 14% response rate, which is rather disappointing. With this limited sample, it is difficult to reach strong conclusions, but nevertheless, some common themes can be gleaned.

The feedback received is summarised in the following paragraphs, with overall conclusions drawn in the next section.

- Of the 17 attendees, the bulk (11) reported attending between 2 and 3 conferences a year, and 14 reported that they attended at least two.
- Of the respondents, about half indicated that they learned of ICMCIS through means other than membership in the IST Panel or its activities. This is positive as the message appears to be reaching people not directly involved in IST activities. Those not reporting that they learned of ICMCIS through the IST Panel, included word of mouth, the internet, and colleagues.

- Of the attendees, 9 reported that this was their first time attending ICMCIS. This is also a healthy indicator, as it means that about half of these 17 people were new to the conference and hence again there is some hope that the message is getting out there to new people.

- Most of the respondents were satisfied with the information available online regarding the conference – score 3.71 out of 5.

- Most of the respondents were satisfied with the information available via email regarding the conference – score 3.82 out of 5.

- Most of the respondents were very satisfied with the information package provided regarding the conference – score 4.12 out of 5.

- Most of the respondents were satisfied with the conference registration process – score 3.88 out of 5.

- Most of the respondents were very satisfied with the social events – score 4.35 out of 5.

- Most of the respondents were very satisfied with the coffee breaks – score 4.35 out of 5.

- Sixteen of the seventeen respondents reported that they had made new network connections that they planned to pursue in the coming year.

- Most of the respondents were satisfied with the range of topics covered in the conference – score 4.18 out of 5.

- Most of the respondents were very satisfied with the keynote speakers and felt they added significantly to the conference – score 4.35 out of 5.

- Most of the respondents felt the conference programme was well organised and the papers were logically grouped – score 4.00 out of 5.

- Most of the respondents felt the industrial participation added to the overall conference programme – score 3.29 out of 5.

- Most of the respondents felt the poster sessions and lightning presentations added to the overall conference programme – score 3.41 out of 5.

- Fourteen respondents reported that they would attend ICMCIS again in the future, while 3 said maybe.

- Fourteen respondents reported that they would recommend ICMCIS as a good place to learn about current matters of interest related to military communication and information systems; three said maybe.

- Attendees felt that the following additional topics should be covered in the conference:

  - Information fusion

  - More on satcom

  - More focused, less topics

  - Security of AI

  - AI robustness and explainable AI

  - Project pitches

  - RF hardware, antennas, propagation were not yet listed in the registration phase

  - Data centricity

  - C2

- More space topics
- More crypto
- "Omni-Domain" approach to defence and security issues. I'm pushing this "Omni Domain" thing, as opposed to the current and, IMHO, unsatisfactory "Multi-Domain" expression.

- Respondents liked the following things best about the conference:
  - Papers presented and location
  - Meeting at the Hotel
  - Availability of the organizers
  - The different tracks
  - The organization
  - Warm welcome and friendly environment
  - Good tracks structure and balanced agenda
  - Venue was good, good coffee breaks
  - The venue was fit for purpose
  - Tracks were well aligned
  - Good location (nice hotel with conference rooms, near restaurants, etc.)
  - The paper selection process ensured high quality work was presented.
  - Informal
  - The general concept
  - Content
  - Key note speech from the Ukrainian attendees was very interesting!

- Respondents thought the poorest aspects of the conference were:
  - Paper template was unclear for a too long time
  - Unclear if IST panel members had to pay conference fee
  - Need more subjects on satcom which key for military communications
  - Not including lunch
  - Unclear registration/payment procedure
  - Instructions and communication before the conference, changing instructions
  - Indoor smoking
  - Nothing
  - Slight delay in releasing paper acceptance notifications
  - There was a lack of chairs for the large group setting. Minor issue.
  - Some of rooms where small, with poor ventilation and LCD screen that was unsuitable for laser pointers – organizers should provide appropriate pointing device for each display technology
  - One session room was too small
  - Registration process
  - Can't tell

- Additional comments included:
  - Thank you for organizing the conference of this scale!
  - Good job!
  - Nothing specific
  - The speakers must be more aware of the military things
  - No
  - Ukraine guest speeches were a very strong item
  - Thanks for organizing!
  - none in particular
  - Stick to time schedules, even when a speaker early, so people can reliably switch tracks without interrupting others
  - Thank you for a great conference!
  - In the future in would like to see participation from the NATO bi-strategic commands and NAC.
  - No
  - Papers should be available before the first presentation
  - Send the final program in advance
  - Please see my point regarding the omni-domain approach point made above]
  - None
- Authors provided the following feedback.
  - There were 108 authors listed in the 30 papers and 7 posters accepted for presentation at the conference. Thirty-six of these attended the conference listing themselves as Authors. Of these 36, only 11 responded to the questionnaire, or about 30.6%.
  - Eleven authors were generally satisfied with the paper submission process – score 3.73 out of 5.
  - Nine authors, who answered the question, were generally satisfied with EasyChair as a tool – score 4.56 out of 5.
  - Nine authors were very satisfied with the deadlines for submissions, reviews, acceptance, etc. – score 4 out of 5.
  - Two authors were not satisfied with the deadlines for submissions, reviews, acceptance, etc., and listed the following as reasons: presentation deadline was too early, usually it's right before the conference or during the conference and that there were discrepancies between the CfP and the online material, discrepancies between the IEEE template and the NATO one, and for the conditionally accepted papers, the final acceptance notification was very late.
- Eight authors were very satisfied with the status information they received throughout the paper submission process – score 4.38 out of 5.
- Eight out of nine authors felt that having their paper published in IEEE Xplore was important.

  One author commented that the final acceptance for the conditionally accepted papers came very late; he had to start preparing his presentation before receiving final acceptance notification of his conditionally accepted paper.

Annex E – ICMCIS 2023 COMMITTEE MEMBERSHIP

E1.0   2023 ICMCIS STEERING COMMITTEE

First Name	Last Name	Affiliation	Nation
Marek	AMANOWICZ	Research and Academic Computer Network (NASK)	Poland
Markus	ANTWEILER	Fraunhofer FKIE	Germany
Gian Luca	FORESTI	University of Udine	Italy
Patrice	GUIVARCH	DGA Maîtrise de l'information	France
Wolfgang	KOCH	Fraunhofer FKIE	Germany
Jerzy	ŁOPATKA	Military University of Technology	Poland
Risto	MÄÄTTÄ	Finnish Defence Research Agency	Finland
Bob	MADAHAR	Defence Science and Technology Laboratory	United Kingdom
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Annex F – ICMCIS CHRONOLOGY

Serial	Year	Country	City	Title	NATO Involvement	Senior NATO Rep	STO Involvement	SC Chair
	1992 – 1996	Poland	Zegrze	National Conference – WKTiL				
1	1997	Poland	Zegrze	National Conference – WKTiL	NATO Involvement Starts – NC3A	Loren Diedrichsen (GM NC3A), Rob van Engelshoven (NC3A)		No SC only TPC
2	1998	Poland	Zegrze	RCMCIS	NATO Support Starts – STC, NC3A, ASG DI	Loren Diedrichsen (GM NC3A), Davraz Yavuz (NC3A), Dag Wilhelmsen (NC3A)		No SC only TPC Member: Dag Wilhelmsen
3	1999	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI Fist time logotype NC3A	Dag Wilhelmsen (NC3A), Barry Brown (NC3A)		No SC only TPC TPC vice chair: Dag Wilhelmsen
4	2000	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI	Peter Lenk (NC3A), Barry Brown (NC3A), Dag Wilhelmsen (NC3A)		No SC only TPC TPC vice chair: Dag Wilhelmsen
5	2001	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI	Peter Dicks (NC3A), Dag Wilhelmsen (NC3A)		No SC only TPC TPC vice chair: Dag Wilhelmsen

Serial	Year	Country	City	Title	NATO Involvement	Senior NATO Rep	STO Involvement	SC Chair
6	2002	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI	Peter Dicks (NC3A), Ken Peebles (Director RTA), Paul Kennedy (NC3A), Barry Brown (NC3A)		No SC only TPC TPC vice chair: Paul Kennedy, Honorary chair: Loren Diedrichsen
7	2003	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI	Luigi Bella (NC3A), Barry Brown (NC3A)		No SC only TPC TPC vice chair: Dag Wilhelmsen, Honorary chair: Loren Diedrichsen
8	2004	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI	Luigi Bella (NC3A), Barry Brown (NC3A)		No SC only TPC TPC vice chair: Luigi Bella, Honorary chair: Loren Diedrichsen
9	2005	Poland	Zegrze	RCMCIS	NATO Support – STC, NC3A, ASG DI	Luigi Bella (NC3A), Dag Wilhelmsen (NC3A), Barry Brown (NC3A)		Advisory Board: Loren Diedrichsen, Dag Wilhelmsen TPC vice chair: Luigi Bella
10	2006	Poland	Gdynia	MCC	NATO Support – NC3A, ASG DI	Dag Wilhelmsen (GM NC3A), Luigi Bella (NC3A), Davraz Yavuz (NC3A), Peter Lenk (NC3A), Marshall Billingslea (ASG DI)		Advisory Board: Loren Diedrichsen, Dag Wilhelmsen TPC vice chair: Luigi Bella

Serial	Year	Country	City	Title	NATO Involvement	Senior NATO Rep	STO Involvement	SC Chair
11	2007	Germany	Bonn	MCC	NATO Support – NC3A, ASG DI	Dag Wilhelmsen (GM NC3A), Luigi Bella (NC3A), Davraz Yavuz (NC3A), Peter Lenk (NC3A), Peter Flory (ASG DI)	IST Panel members involvement in MCC – Juergen Grosche (IST Panel NATO STO)	Advisory Board: Loren Diedrichsen, Dag Wilhelmsen TPC chair: Juergen Grosche, vice chair: Luigi Bella
12	2008	Poland	Krakow	MCC	NATO Support – NC3A, ASG DI	Dag Wilhelmsen (GM NC3A), Luigi Bella (NC3A), Peter Lenk (NC3A), Peter Flory (ASG DI)	IST Panel members involvement in MCC – Juergen Grosche (IST Panel NATO STO)	Chair Juergen Grosche Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen
13	2009	Czech Republic	Prague	MCC	NATO Support – NC3A, NATO HQ C3S	Dag Wilhelmsen (GM NC3A), Luigi Bella (NC3A), Peter Lenk (NC3A), Glynne Hines (NATO HQC3S)	IST Panel members involvement in MCC Juergen Grosche (IST Panel NATO STO)	Chair Juergen Grosche Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen
14	2010	Poland	Wrocław	MCC	NATO Support – NC3A	Dag Wilhelmsen (GM NC3A), Luigi Bella (NC3A), Peter Lenk (NC3A), Gerlof de Wilde (EDA)	RTO members involvement in MCC Robert Walker (Chair NATO R&T Board), Albert Husniaux (director NATO R&T Agency), Juergen Grosche (IST Panel NATO STO)	Chair Juergen GroscheHonorary Chairs: Loren Diedrichen, Dag Wilhelmsen

Serial	Year	Country	City	Title	NATO Involvement	Senior NATO Rep	STO Involvement	SC Chair
15	2011	NC3A & Netherlands MoD	Amsterdam	MCC	NATO Support – NC3A	George D'Hollander (GM NC3A), Luigi Bella (NC3A), Peter Lenk (NC3A)	IST Panel members involvement in MCC	Chair Juergen Grosche Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen
16	2012	Poland	Gdańsk	MCC	NATO Support – NC3A	Dag Wilhelmsen (NCIA) Luigi Bella (NCIA), Peter Lenk (NCIA)	IST Panel members involvement in MCC	Chair Juergen Grosche Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen
17	2013	France	Saint Malo	MCC	NATO Support – NC3A	Peter Lenk (NCIA), Serge Baso (NATO), Michael Sieber (EDA)	IST Panel members involvement in MCC	Chair Juergen Grosche Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen
	2014	No Conference		Shifted from Autumn to Spring				
18	2015	Poland	Krakow	ICMCIS	NATO Support – NCIA, IST Panel	Charles Shawcross (NCIA), Peter Lenk (NCIA), Michael Sieber (EDA)	IST Panel members involvement in MCC	Chair Juergen Grosche Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen
19	2016	Belgium	Brussel	ICMCIS	NATO Support – NCIA, IST Panel	Michael Sieber (EDA) Peter Lenk (NCIA)	MGen Albert Husniaux (NATO Chief Scientist) In conjunction with IST Panel	Chair: Dr Peter Lenk Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen,

Serial	Year	Country	City	Title	NATO Involvement	Senior NATO Rep	STO Involvement	SC Chair
20	2017	Finland	Oulo	ICMCIS	NATO Support – NCIA, IST Panel	Peter Lenk (NCIA)	Allan Schafer (Director CSO), In conjunction with IST Panel	Chair: Peter Lenk Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen, Juergen Grosche
21	2018	Poland	Warsaw	ICMCIS 20th Anniversary	NATO Support – NCIA, CSO, IST Panel	Peter Lenk (NCIA)	Dr Thomas Killian (NATO Chief Scientist), In conjunction with IST Panel	Chair: Peter Lenk Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen, Juergen Grosche
22	2019	Montenegro	Budva	ICMCIS	NATO Support – NCIA, CSO, IST Panel	Peter Lenk (NCIA)	In conjunction with IST Panel	Chair: Peter Lenk Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen, Juergen Grosche
	2020	No Conference	Amsterdam	Cancelled due to COVID	NATO Support – NCIA, CSO, IST Panel			
23	2021	NCIA	Oeiras	ICMCIS Virtual due to COVID	NATO Support – NCIA, CSO, IST Panel	Peter Lenk (NCIA)	Dr Brian Wells (NATO Chief Scientist), In conjunction with IST Panel	Chair: Peter Lenk Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen, Juergen Grosche
24	2022	Italy	Udine	ICMCIS	NATO Support – NCIA, CSO, IST Panel	Peter Lenk (NCIA)	John-Mikal Størdal (Director CSO), In conjunction with IST Panel	Chair: Peter Lenk Honorary Chairs: Loren Diedrichen, Dag Wilhelmsen, Juergen Grosche

Serial	Year	Country	City	Title	NATO Involvement	Senior NATO Rep	STO Involvement	SC Chair
25	2023	North Macedonia	Skopje	ICMCIS	NATO Support – NCIA, CSO, IST Panel	Michael Street (NCIA)	John-Mikal Størdal (Director CSO), Official STO Event, RSY under the IST Panel	Co Chairs: Antoine Smallegange and Latasha Solomon

Annex G – ICMCIS 2023 TECHNICAL KEYWORDS

The following is a list of keywords extracted from each of the accepted papers and poster sessions. Using Chat-GPT, the list was de-duplicated and arranged in alphabetical order.

5G, 6G, AdaBoost, Algorithmic efficiency, APP-11, Autoencoder, Benchmark, BERT, Big Data, CEM, Coalition Networks, Communications Management, Controller Placement Problem, Covert Communications, Cyberdefence, Cybersecurity, Data Catalogue, Data Lake, Decision Making, Decision Tree, Deep Learning, Deepfake News, Deployment Orchestration, Disadvantaged Tactical Networks, Directional Networking, Disinformation, DOTMLPFI, Drone Technology, Electronic Warfare, Equalizers, Federated and Adaptive Cloud Architectures, Field Medical Card (FMC), Fine-Tuning, Free Space Optical Communications, Frequency Hopping, GIS Software, Hardware-in-the-Loop, High Frequency, Information Dissemination, Information Platform, Infrastructure as Code, Interference, Internet of Battlefield Things (IoBT), Iterative Algorithms, Jamming, Jamming Systems, KNN, Link Degradation, Machine Learning, MANET, Markov Chains, Medical Evacuation, MEDEVAC, Metadata, Military Business Intelligence, Military Operation in Urban Terrain, Military Use Cases, MLP, Mobility, MIST-AT, Multi-Domain Operations, Named Entity Recognition, NATO Digital Transformation, Neural Networks, Non-Line-of-Sight, Online Planning and Acting, Optical Wireless Communications, Optimization Methods, Patient Movement Request (PMR), Patient Tracking Message (PTM), Performance Indicators, PNT, Protected Core Networking, Quantum Computing, Quantum Information Science, Ranging, Reinforcement Learning, RoBERTa, Sankey Diagram, Scheduling, Search Problems, Self-Interference, Sensor Data, SF-STAR, Signal Interception, Situational Awareness, Situational Assessment, Social Network Analysis, Software Defined Network, Software Defined Radios, Spatio-Temporal Clustering, Temporal Analysis, Transformers, V2X, VANET, VHF-Networks, Visual Analytics, Visible Light Communications, YOLOv8 Algorithm.