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The FOI C4ISR Demonstration 2008

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Abstract – *In this paper, we describe the C4ISR demonstration performed by FOI in 2008. The demonstration combined the results from research projects on surveillance, communication and information fusion. A scenario where Swedish forces conduct peace-support operations in a fictitious country was used. Both low and high-level information fusion was demonstrated. Data from synthetic-aperture radar, underwater surveillance systems, video surveillance and intelligence information was fused using Impactorium, which allowed users to sort and filter reports and perform a threat assessment. Forensic analysis using video data was also shown, as well as semantic queries using the Semantic Milwiki. Evaluations of the demonstrations show that research in sensor, communication and fusion system is relevant to the current and future missions of the Swedish Armed Forces.*

Keywords: Decision support systems, information fusion, ground surveillance, urban surveillance, underwater surveillance, situation assessment, threat assessment.

1 Introduction

In this paper, we describe the C4ISR demonstration Led-DoV performed by the Swedish Defence Research Agency (FOI) in 2008. The demonstration combined the results from research projects on urban and underwater surveillance, communication and information fusion and showed how the research results fit together in a vision of a future command and control system of the Swedish Armed Forces. The inclusion of fusion capabilities in the demonstration made it possible to show all the research results in a combined scenario and added considerably to the realism of the scenario. The Impactorium system developed by FOI was used to fuse information from underwater surveillance systems, video surveillance, synthetic aperture radar images, and intelligence reports input by humans.

In total, the demonstration was performed for six different groups of participants from the Swedish Armed Forces as well as the Swedish Defence Procurement Agency and civil authorities. In addition to displaying the results from the research projects, the demonstrations were also used to get input from the attendees about the results in the form of a questionnaire as well as a discussion session after each demonstration.

The demonstration showed how the results from the different research projects could be combined. The benefits of fusion in future C4ISR systems were also demonstrated. Fusion was performed both on a low-level, using data from different sensors, and on a high-level, where sensor information was combined with soft data from HUMINT (human intelligence) and OSINT (open source intelligence).

This paper is outlined as follows. First we give brief information about the scenario used in the demonstration and about previous Swedish fusion demonstrators. Section 2 presents an overview of the system architecture used, while section 3 provides a walk-through of the demonstration scenario while simultaneously giving some information about the different components of the system. No technical details are given, for this we refer to the cited references. Finally, section 4 gives a summary of the results of demonstrator evaluations and gives some suggestions for future demonstrations.

1.1 Scenario

The scenario used in the demonstration was adapted from a standard scenario used by the Swedish Armed Forces in the Combined Joint Staff Exercises. The setting is a fictitious country ("Bogaland") where two ethnic groups have a history of civil war and persecutions. In addition to religious and ethnic conflicts within Bogaland, there is also an economic conflict concerning the natural resources in the form of oil. A peace-agreement has been signed by the parties and an international force ("BFOR") is present to enforce the agreement and conduct peace-support operations. Irreg-

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ular groups in Bogaland seek to preserve or increase their influence by undermining the efforts of BFOR, the lawful government or competing irregulars. Two of the neighboring countries have much at stake in the conflict, because of economic interests and shared identities with parties within Bogaland. Actors within these neighboring countries support irregulars in Bogaland. Bogaland has been used as a scenario for several years and there is hence a large amount of background history available, including detailed information about the different warring factions and their leaders. Geographically, Bogaland consists of the mid-east portions of Sweden. In the scenario used in the demonstration, most of the events occurred in or around the city of Norrköping in the east of Sweden.

1.2 Previous Swedish fusion demonstrators

FOI has throughout the years performed several information fusion demonstrations. The FOI Information Fusion Demonstator 2003 was an ambitious demonstration of force aggregation, sensor management and particle filtering in a ”cold-war”-type scenario [1]. In 2005, a demonstration of a fusion system including an ontology-based query language and an extension of the sensor management from the 2003 demonstration was performed [2, 16], and in 2006 a demonstration of capabilities-based classification and user-centric situation awareness took place. Both the latter two demonstrations used operations other than war (OOTW) type scenarios similar to the Bogaland scenario used in the current demonstration.

2 System overview

The demonstration integrated research results from a number of different projects at FOI.

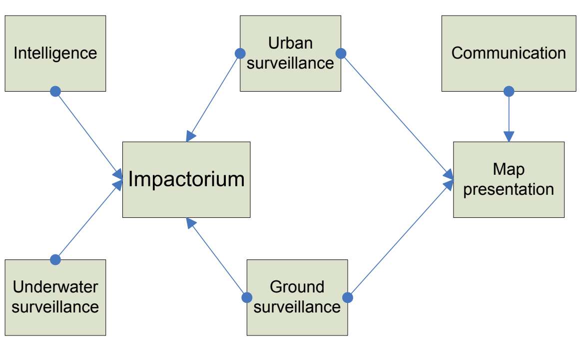

Figure 1: This picture shows how the different subsystems were connected. Results from the different sensor systems were fed into Impactorium, which used them to perform threat assessment. Results from some sensor systems as well as from the communication demonstration subsystem were displayed on a traditional map display.

Figure 1 shows a conceptual view of the demonstration system. The different components are

- Ground surveillance system, described in section 3.1.
- Underwater surveillance system, described in section 3.2.
- Urban surveillance and fusion system, described in section 3.3.
- Impactorium system for threat assessment and fusion of intelligence and sensor reports described in section 3.
- Communication demonstration subsystem, described in section 3.4.
- A traditional map display system, where the locations of reports and communication was displayed.
- A simulated intelligence unit, which input HUMINT and OSINT information to Impactorium.

Each involved subsystem has its own operator display. In addition, two systems were used to display situation awareness information to commanders and analysts at a higher level. A traditional map display was used to display sensor reports and conclusions from the urban sensor system fusion node on top of a map of the operations area. In addition to displaying information on a map, it was also possible to get a 3D view of the city where the scenario took place. Intelligence analysts and commanders at the FHQ (force headquarters) should also have access to a decision support tool that fuses and displays information. In our case, Impactorium served this role.

3 Decision support system

The Impactorium system [5, 20], developed by the FOI research project on information fusion, was used to fuse information from sensors, low-level fusion systems, and HUMINT in the demonstration. Impactorium is a collection of software tools used to demonstrate information fusion capability, mainly for OOTW.

The user interface of the tool is shown in Figure 2. On the left, events of interest selected by the user are shown in a matrix display based on the a priori probability and estimated severity of the event. Bottom left shows more details about the currently selected event(s). On the right, the observation reports from sensors and humans are shown in a list, on a map and in more detail. It is possible to only select those reports that are connected to the selected event(s) for display.

In order to connect the reports to the events of interest, Impactorium uses threat models and indicators. In the current version of the tool, the threat models are Bayesian belief networks (BBN). All reports are classified with indicators

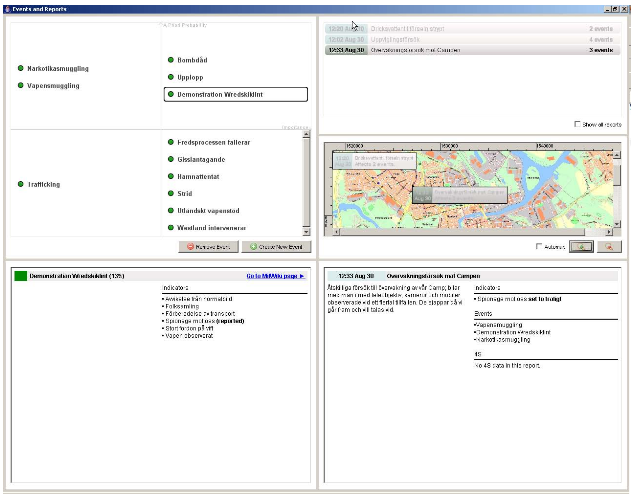

Figure 2: User interface of the Impactorium tool.

taken from an indicator ontology. The indicators are used to connect the reports to nodes in the BBN's. Each indicator also has an associated value, which is set by fusing the reports with that indicator. Probabilities for events are then computed based on the values of the indicators and the conditional probability tables that are specified in the threat model. An example threat model is shown in Figure 3.

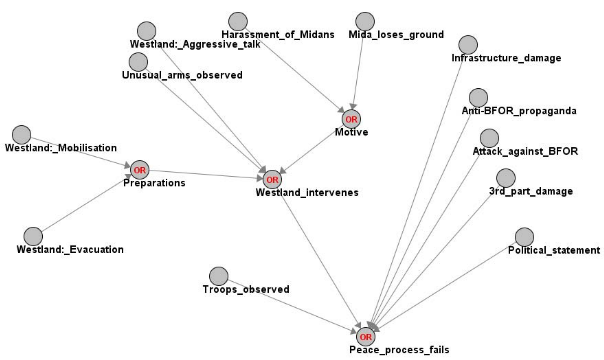

Figure 3: Threat model (Bayesian belief network) for use in Impactorium.

Threat models for the demonstration were generated in collaboration with a retired intelligence expert. The subject-matter expert was given some details about Bogaland as well as the result of a system analysis of the current scenario that had been performed by FOI analysts. The intelligence expert listed a number of different events of interest and provided indicators for each of these. In the demonstration, Impactorium received several different kinds of input

- The operators of the ground surveillance and underwater surveillance systems used the report editor tool to send observation reports (including indicators) when they had seen something interesting. For example, at one point in the scenario the change-detection of the synthetic-aperture radar determined that a military bridge had been placed over Göta Kanal. This was reported to Impactorium, where it increased the probability of combat.

- The most interesting alarms generated by the automatic fusion system in the urban surveillance were transmitted to Impactorium.

- Reports written by intelligence analysts were also input to Impactorium. This happened, for instance, at the start of the scenario, where police investigations had given some evidence that drug smuggling was taking place. This report was also used to guide the ground surveillance system to confirm the smuggling.

In addition, the demonstration simulated using open source intelligence collection from the web.

3.1 Ground surveillance

The FOI research project on ground surveillance addresses capabilities and performances in co-operating sensor systems used for ground situational picture. This includes how models of sensors, targets, terrain etc can be used in assessment situations. At the demonstration, an example of mission planning of sensor resources to improve situation awareness as well as the use of difference analysis of SAR (Synthetic Aperture Radar) and recognition and re-recognition in video-images from a UAV-borne (Unmanned Aerial Vehicle) EO-sensor (Electro-Optical) was shown.

This activity started when an intelligence report stating that a warlord was preparing a large-scale drug smuggling operation was fused with police information about a drug manufacturing site somewhere north of the city. This lead to the intelligence question "We suspect that drugs are manufactured in the area north of the city and that it is smuggled into the city. Is it possible to verify this and find out locations, transport routes, how often etc."

The resulting planning was expressed in a number of steps. The later steps need to be started from a high readiness state to minimize the delays between sensors. This in turn maximizes the chances for success. In our scenario there were a limited number of sensors of different types available to use. The questions are complex and area specifications are vague. We need both area coverage and high resolution on specific objects in addition to endurance. None of the sensors are capable of this alone.

In step one, we used different types of SAR-sensors carried by satellites and aircrafts/UAV's with long endurance (more than a week). One to two images per day is required in order to be able to establish the normal picture and discriminate the suspected activity from the background noise. These SAR images were analyzed by various difference analysis methods, followed by a-priori correlation and hypothesis generation and matching process. See Figure 4 for an example.

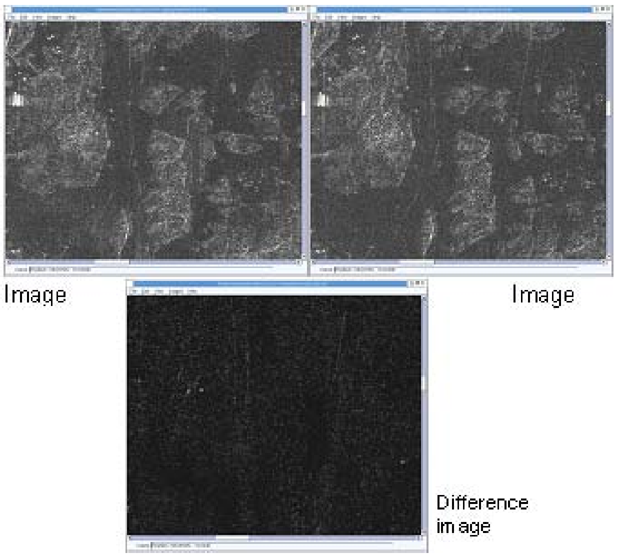

Figure 4: Two VHF SAR images and a difference image showing objects that where added in image 2.

In step two, we used acoustic and seismic sensors which were placed close to road junctions surrounding the suspected areas. This gives information about the traffic flow. In the scenario there was a problem to protect the sensors from being destroyed or stolen in outlaw areas. At step two we also planned to use a UAV-carried 3D-laser to identify a few hidden objects under foliage which had been detected by the low frequency SAR sensor.

In step three we detected, classified and followed individual vehicles by using EO-sensors on UAV's in the area during periods suggested by the reconnaissance in step two. This was for later re-identification during surveillance of the roads towards the city, which was also carried out in a similar way after the same kind of planning. Inside the city we established a network of surveillance cameras to record terrorist acts and enable us to track vehicles back to their starting positions. In situations such as these, there is a need to interact with the local authorities to get support for the deployment of our sensors and also to let us, if possible, gain access to cameras already in use by others. These surveillance cameras will later be used by the urban surveillance system to detect interesting events.

In the scenario, the SAR and the 3D laser images verified that there was indeed a drug manufacturing site north of the city. This was reported to the Impactorium tool and further strengthened the hypothesis that drug activities were taking place. In addition, when analyzing the SAR images it was apparent that a bridge had been built over Göta Kanal. This was reported into Impactorium. Together with information about a militia convoy north-west of the city, this was seen as a possible indication of future combat, since the bridge could be used to transport heavy vehicles across the river.

The sensor resource planning discussed here can be done in many ways depending on task priorities and what sensors and sensor carriers are available. We have started to develop a methodology to do it more systematically and to define supporting tools. This planning is one aspect of a more general sensor management and control system needed to implement a general ground surveillance system [7, 8]. At this stage in the demonstration, enough evidence had come into the Impactorium system to enable it to confirm the hypothesis that drug smuggling was taking place.

3.2 Underwater surveillance

The main use of underwater sensors is the surveillance of the underwater domain, though they may also complement above-water sensors for the surveillance of the sea-surface. In close coastal or harbor environments surveillance is often a challenge, which requires solutions different from conventional blue-water surveillance. There are many reasons for this; one is that surveillance in shallow waters is very much influenced by the interaction of the propagating waves with the sea-floor. Factors such as sea-bed characteristics, topography and ambient noise put limits to the performance of the surveillance systems. In addition, the time-variability of the conditions in the waters can be large. Being close to shore means higher ambient noise due the anthropogenic sources. One way of mitigating these challenges is to increase the robustness by using many different types of sensors, and utilize the possibilities that data-fusion give.

At the demonstration, two examples of underwater surveillance were given. In the first example, underwater sensors were placed on the sea-floor in the approaches to the harbor with the purpose to give advanced warning of the passage of a suspected ship. The sensors were placed at a point where a passage typically gives 1-1 h advance warning before the ship enters the port. In this case, the underwater sensors were used to detect passages of ships, and also to classify the ships. FOI has previously put considerable effort into the development of methods that make use of fusion on data recorded by underwater electrode sensors and hydrophones for the classification of surface ships [11, 12, 13, 14]. Our results (see Figure 5) indicate that in order to obtain a performance gain (i.e., achieve a higher probability of correct classification) when using data fusion, the performance of the individual sensors have to be fairly equal. If one of the sensors has a significant better performance than the others, fusion may degrade that performance, and it would have been better to use only the best sensor.

The other example of underwater surveillance given at the demonstration was a case where a ship that was sus-

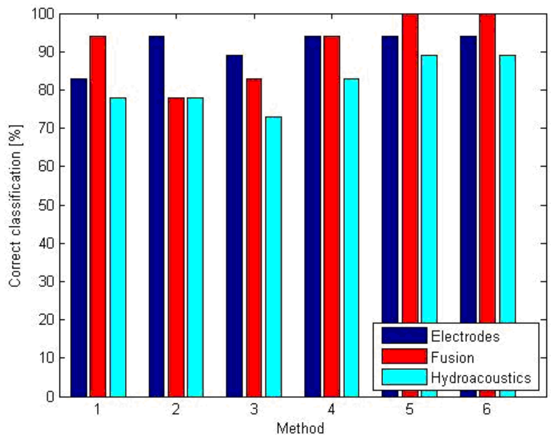

Figure 5: Classification correctness for different methods, from [12] .Methods 1-3 are based on features extracted using an Auto Regressive model, methods 4-6 on features from a Delay Differential Equation model. For Method 1 and 4 fusion is done using Bayes' combination rule, for Method 2 and 5 voting is used and for Method 3 and 6 VIP voting is used. For each method, both the results of individual sensors and fused results from the two sensors are shown. Fusion performs better only when the two sensors have equal performance characteristics.

pected to be part in smuggling had anchored inside the harbor. The waters surrounding the ship are surveyed looking for the potential presence of divers that could be engaged in smuggling goods from the ship to the shore. The problem of diver detection in harbors has received a lot of attention recently [9]. Figure 6 shows a display from a diver detection sonar, with two divers swimming through the insonified water volume. The challenge for this type of surveillance is two-fold. Firstly, divers are inherently low-signature targets, which cause difficulties in the noisy harbor environment. This noise background has to be fully understood, and the detection algorithms must be made insensitive to the noise. Secondly, we use a multitude of different sensors and we must find the best way to combine them in order to achieve the best performance. To be specific, this is a question of how to complement the main instrument for diver detection, the active sonar, with other types of sensors and utilize fusion in the best way for this purpose. The results so far show that the performance of the active sonars has large time variability due to changing water conditions and reverberation from wakes and the surroundings. Passive acoustic and electromagnetic arrays can detect divers but with very short ranges. However, situations may arise when the acoustic ambient noise is high while the electromagnetic is low and vice versa. Therefore, our measurements indicate that robustness is achieved by a combination of all these surveillance means. This is an ongoing effort that will continue for the next few years.

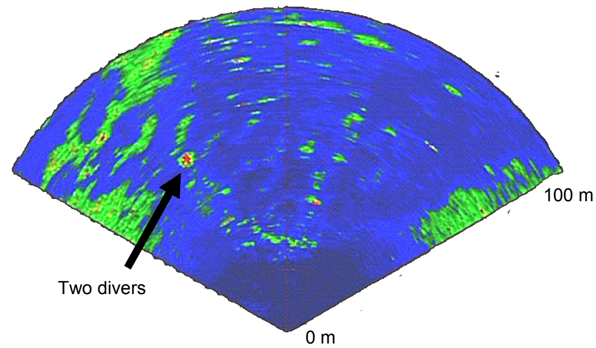

Figure 6: Figure 6. Image from an active sonar in a harbor showing two divers.

Both the passage of the ship outside the shore and the detected divers were reported to Impactorium. Together with the intelligence reports about a convoy north of the city mentioned earlier, this caused an increase of the probability of armed combat taking place.

3.3 Urban Sensor System

The infrastructure for urban surveillance during time-limited, peace-keeping missions differs significantly from permanent installations. The requirements on rapid sensor deployment imply that the operation of at least part of the sensor systems will need to rely on low-bandwidth and delayed, wireless communication channels. On-line sensor monitoring does not exist. Instead, sensors collaborate autonomously at squares, communication terminals, major intersections, and other geographically confined areas to track activities. Decision support tools are needed to interpret the data from the sensor network and to relieve the operator from having to monitor the sensor data continuously. Algorithms for automatic detection of anomalies are used to send alarms to a network-distant operator.

In the demonstration we showed how a fictitious operator used the urban sensor system, first to notice potential dangers by receiving alarms, second to analyze the events behind the alarms. The operator monitored a real-time alarm screen with a map background, and another screen with analysis tools. The received alarms were generated automatically by fusion algorithms that in a distributed fashion work in the sensor network. Examples of such alarms are gunfire, fighting, detection of weapons, and so on. For particularly interesting alarms, the operator could investigate more closely by ordering extra sensor information from the sensors. The extra information, for instance a video sequence or an acoustic taking, was then propagated over the network from sensor to operator for a noticeable communication cost. If the causes of the alarm are found to be severe, the alarm was tagged with indicators and forwarded to the commanding officer as well as to the Impactorium system.

3.3.1 Automatic weapon detection using fusion

Co-located high resolution radar and optical sensors give the possibility to automatically detect weapons and identify persons as suspected carriers of weapons. The radar is used for detecting unusual metallic objects. The optical sensor is used to reduce the number of uninteresting radar reflections and give information on the appearance of the suspected persons. In the demonstration, the procedure for detecting unusual metallic objects was as follows:

1. When the radar detects reflections of high intensity (above a certain threshold value) an alarm appeared for the operator on the alarm screen.
2. The operator then requested radar and optical images from the sensor network through the analysis tools in order to do a detailed analysis.
3. The operator verified whether weapons are present in the scene.
4. Information on the appearance of the suspected persons was given from the optical sensor.

To reduce the number of uninteresting radar reflections the radar and optical images were automatically fused. The data fusion will facilitate the subsequent analysis of the radar image. The fusion procedure was as follows:

1. Image registration of the radar and optical sensors has been performed in advance.
2. The persons in the scene are automatically detected using foreground subtraction in the optical image [4] and their silhouettes are extracted.
3. The silhouettes are automatically fused with the radar image. The fusion procedure takes into consideration that the visible image has higher resolution than the radar image, i.e. the visible image give more detailed information than the radar image.

By using the radar technique it is possible to detect large weapons [10], but difficult to detect small weapons (like pistols). There is also a risk of false alarms within the silhouettes because the human body itself causes radar reflections of various intensities. Further work will include methods for reducing the number of false alarms also within the silhouettes. A 3D optical model of a person will be used to see whether the existence of a weapon will cause a lack of symmetry of the modeled person. A possible operational view of a scene, as a result of automatic weapon detection, is presented in Figure 7.

In the demonstration, weapons were detected near a square on people gathering near a square in the city. Together with information from intelligence sources on the mood of the citizens of the city, the report of the weapons detection was fused in Impactorium. The result was a warning that the probability of riots was increased.

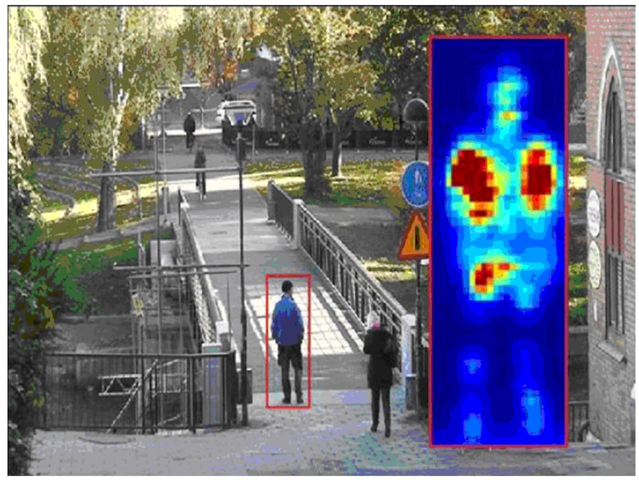

Figure 7: Information given to the operator as a result of automatic weapon detection. The radar image is presented to the right.

3.3.2 Forensic database search

At this stage in the scenario, there were other strong indications that dangerous events were about to take place in the city. Two things now happened in the scenario. First, a sabotage against the communication systems in the city forced us to use mobile ad hoc networking instead of relying on the central communication antenna (see section 3.4 below). Second, a car-bomb exploded. The explosion was detected and localized by acoustic sensors placed around the square. The operator immediately requested video stored in surveillance cameras at the square through one of the analysis tools. The memory banks of the cameras were still reachable over the sensor network. The video showed, instants before the camera is out, how a white Volvo explodes - a car bomb.

The operator then entered a forensic mode on the analysis tool with the purpose to backtrack the car to the bomb workshop. At the time the car entered the square it was automatically tracked by the sensor system, so the operator could, without ordering more video, conclude that the car parked at the square at 9.23 a.m. He then requested a distributed database search in all sensor memory banks to find the white Volvo. The search was constrained temporally and spatially by the fact that the car entered the square shortly before 9.23. Also, both imagery and acoustics from the square sensors supported the search. Although the urban sensors covered less than 5% of the city area in the demonstration, the database search finds the Volvo in video cameras along the car's voyage from the bomb workshop to the square. Fusion algorithms were used for automatically re-recognizing the car in the video cameras. Thus, the workshop was localized and other cars that have left the workshop were immediately tracked in an attempt to minimize the damage of additional bombs.

After the car bomb had exploded, there was a need to do a forensic analysis to determine where the car came from and who is responsible for the car bomb. In the demonstration, we also showed how semantic techniques could be used to get information about relevant events from an intelligence database. The semantic Milwiki system [15] developed by the information fusion research project at FOI was used. A semantic query that aimed to capture relevant intelligence reports was formulated and results shown.

3.4 Communication

Many tactical scenarios require mobile communications in areas without fixed infrastructure, such as base stations or central nodes. For these situations ad hoc-networks is an attractive concept. An ad hoc network is a collection of wireless mobile nodes that dynamically form a network without the need for any pre-existing network infrastructure or centralized administration. Due to the limited transmission range of mobile radios, only nodes that are close to each other can communicate directly. In ad hoc networks this is solved by the use of relaying nodes, multihop technology, where nodes within range relay the message to the receiver across the network [18].

Mobile communications with low antenna heights at both transmitter and receiver is more challenging from a wave propagation point of view than scenarios with elevated base stations, e.g., cellular communication systems. In an urban environment, line-of-sight (LOS) between transmitter and receiver rarely exists with low antenna heights, and thus the received signal is often heavily attenuated and varying over time (fading).

The robustness of wireless communication systems is strongly related to the frequency they operate on. Frequencies in the upper VHF and lower UHF regions are very attractive for mobile tactical networks, as a trade off between range and data rate. The absolute bandwidth available for a communication system in this frequency range is, however, quite limited. Thus, to meet the demands for high data rates, spectral efficiency is very important and multiple-input multiple-output (MIMO) communication systems is a very promising way to achieve this. In MIMO communications multiple antennas are used at both the transmitter and receiver. In fading environments MIMO systems have shown to offer a large increase in capacity and robustness over traditional single-input single-output (SISO) systems [19, 6]. In theory, the capacity increases linearly with the minimum of the number of transmit and receive antennas. However, in real environments, the achievable capacity depends on the radio-channel characteristics [3].

In the demonstration the communication capacity between a moving patrol vehicle and the central command post was shown. The available communication capacity was shown as video quality. The wave propagation between transmitter and receiver was calculated with a model derived from MIMO-measurements performed in Linköping. Three different technology solutions were shown:

- direct communication between the vehicle and central command post
- multihop technology, i.e., nodes can relay messages
- multihop technology used together with MIMO

When only direct communication between the vehicle and central is possible they will lose connection when the vehicle moves out of range. With the multihop technology, the network connectivity is improved, so that intermediate radio nodes relay the message to the receiver. MIMO can be used at the individual links to increase the data rate and hence the video quality in the demonstration. The capacity gains of using MIMO in ad hoc networks have been investigated in [17]. In the demonstration, the positions of the nodes in the network were shown at a map together with the possible communication links and their available capacity, see Figure 8. The route of the relayed message in the network was also shown. The simulated video quality for the three different technology solutions was shown together with the data rate. In the demonstration it was clear that the use of multiple hops and MIMO improved the performance of a communication network, concerning range, robustness as well as data rate.

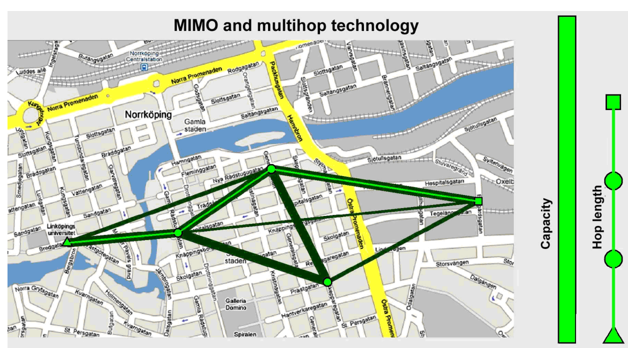

Figure 8: Communication links between nodes. The line width corresponds to data rate and the highlighted green line shows the route for the message.

4 Summary and discussion

In summary, we briefly described the FOI C4ISR demonstration that took place in November 2008. Research results from several different projects from the command and control and sensor research programs of the Swedish Armed Forces were integrated and an OOTW scenario used to show how the sensor, communication and fusion systems together help users achieve increased situation awareness.

The evaluations of the demonstrations showed clearly that the results presented were relevant for the current and future missions of the Swedish Armed Forces. The demonstration was evaluated by a questionnaire that was distributed to all attendees at the six demonstrations. The questionnaire contained both specific questions (one example is that the respondents were asked to quantify the importance of communication reliability if it also reduced transfer speed) and sections for general comments on the research shown and identified needs for future research. These comments were complemented by discussion sessions after the demonstrations. A general consensus of the users was that the results shown were useful, and that the integration of research results from different research programs in a joint demonstration was a good way of showing how a future command and control system could be designed. The data integration and fusion capability shown was regarded as a vital part of future systems. Joint situation pictures were asked for, as well as better ways of handling collected sensor data from different times and locations.

The demonstrations were attended by some representatives from civilian authorities. Both they and military personnel believed that the research results shown would also be useful for civilian applications.

We believe that it is important to perform similar demonstrations in the future. In addition to showing how the applied research at FOI can be useful for our customer, the work involved in preparing the demonstration is a good opportunity for interdisciplinary contacts which leads to new research ideas. In the future, it would be interesting to extend the scope of the demonstration to also include information operations such as computer-network attacks or psychological operations. It would also be interesting to connect the research results presented here with those in earlier FOI fusion demonstrations.

References

[1] S. Ahlberg, P. Hörling, K. Johansson, K Jö]red, H. Kjellström, C. Mårtenson, G. Neider, J. Schubert, P. Svenson, P. Svensson, J. Walter, "An information fusion demonstrator for tactical intelligence processing in network-based defense", *Information Fusion* Vol 8, no 1 (2007) 84-107

[2] K. Camara, E. Jungert, "A visual query language for dynamic processes applied to a scenario driven environment", *Journal of Visual Languages and Computing*, Vol. 18, no. 3, (2007), p. 315-338

[3] D. Chizhik, J. Ling, D. Samardzija, and R. A. Valenzuela, "Spatial and polarization characterization of MIMO channels in rural environment," *in Proc. 61st IEEE Veh. Technol. Conf. (VTC '05 Spring)*, vol. 1, Stockholm, Sweden, May 2005, pp. 161-164.

[4] J. W., Davis, V., Sharma, "Background-subtraction using contour-based fusion of thermal and visible imagery", *Computer Vision and Image Understanding*, Vol. 106, , pp. 162-182, 2007.

[5] R. Forsgren, L. Kaati, C. Mårtenson, P. Svenson, E. Tjörnhammar, "An overview of the Impactorium tools 2008", *Skövde Workshop on Information Fusion Topics (SWIFT 2008)*, Skövde 4-6 november 2008

[6] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Commun.*, vol. 6, no. 3, pp. 311-335, 1998.

[7] P. Grahn, L. Svensson, "An approach to multi sensor ground surveillance", *Second Int. conf. On Military Technology"*, Stockholm, 25-26 October 2005, pp. 117-124

[8] P. Grahn, F. Lantz, "Sensor management and control in multi sensor ground surveillance", *Stockholm Contributions in Military-Technology 2007*, Ed. M. Norsell, National Defence College, Stockolm, ISBN 978-91-85401-93-2, pp.99-111

[9] R. T. Kessel, "Protection in Ports: Countering Underwater Intruders", *Undersea Defence Technology Europe*, Naples, 5-7 June 2007

[10] J. Kjellgren, On 3D-radar data visualization and merging with camera images, *Proc. SPIE Millimeters Wave and Terahertz Sensors and Technology* , Vol. 7117, 2008, pp. G1-G12.

[11] D. Lindgren, R. K. Lennartsson, L. Persson, "Improved Ship Classification in Littorals Through Sensor Fusion", *Sea Technology*, Vol. 48, No. 6, pp.33-38, June 2007

[12] R. K. Lennartsson, E. Dalberg, D. Lindgren, L. Persson, "Improved Classification Ability in Littoral Environments by Decision Fusion", *OCEANS 2007 - Europe*, 18-21 June 2007 Page(s):1 - 5

[13] D. Lindgren, E. Dalberg, R. I. Lennartsson, M.J. Levonen, L. Persson, "Surface Ship Classification in a Littoral Environment using Fusion of Hydroacoustic and Electromagnetic Data", *OCEANS 2006* 18-21 Sept. 2006 Page(s):1 - 5

[14] R. K. Lennartsson, E. Dalberg, M. J. Levonen, D. Lindgren, L. Persson, ”Fused Classification of Surface Ships Based on Hydroacoustic and Electromagnetic”, *OCEANS 2006 - Asia Pacific* 16-19 May 2006 Page(s):1 - 5

[15] C. Mårtenson, A. Horndahl, ”Using semantic technology in intelligence analysis”, *Skövde Workshop on Information Fusion Topics (SWIFT 2008)*, Skövde 4-6 november 2008

[16] C. Mårtenson, P. Svenson, ”Evaluating sensor allocations using equivalence classes of multi-target paths”, *Eighth International Conference on Information Fusion (FUSION 2005)*, Paper B9-1

[17] J. Nilsson, O. Tronarp, G. Eriksson, P. Holm, E. Löfsved, J. Rantakokko, ”Link and network capacity gains in ad hoc networks utilizing MIMO-techniques”. *MILCOM*, Orlando, FL, USA, pp. 1-8, Oct 2007.

[18] E. Royer and C. Toh, ”A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks”, *IEEE Personal Communications*, vol. 6, no. 2, pp. 46-55, April 1999

[19] H. Winters, ”On the capacity of radio communications systems with diversity in rayleigh fading environments”, *IEEE J. Select. Areas Commun.*, vol. 5, pp. 871-878, Jun. 1987.

[20] P Svenson, T Berg, P Hörling, M Malm, C Mårtenson, ”Using the impact matrix for predictive situational awareness”, *10th International Conference on Information Fusion (FUSION 2007)*, 2007