Targeting Situational Awareness beyond the Event Horizon by Means of Sensor Element Munition

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Abstract — **The main input of this paper is to examine a solution for acquiring data from beyond Event Horizon in an area of interest while operating in low-level operations in a given battlespace. As the pace of modern warfare increases, so does the necessity for maintaining accurately and timely updated Situational Awareness as well. Especially in tactical operations, the need for relevant reconnaissance data is critical in fostering effective decision making, and in this data collecting and analyzing process sensors capable of being deployable above an enemy territory play an important role. Versatile military operations in the modern battlespace strive for real-time information about enemy actions. Sensors capable of detecting seismic, acoustic and magnetic phenomena can be deployed to hostile areas with the assistance of mortars and howitzers. This paper describes basic principles concerning Sensor Element Munitions (SEMs) and discusses utilizing Sensor Elements (SEs) capable of sensing motion, magnetic, infrared and electro-optical phenomena and transmitting the accrued data to command posts in real-time to offer data and tools for rapid decision making to facilitate mission success. Rapidly deployable airborne SEMs represent versatile tools for low-level battalion and company operations.**

Keywords - Situational Awareness (SA); Common Operational Picture (COP); Sensors; Sensor Element Munitions (SEMs); Sensor Elements (SEs).

I. Introduction and Definitions

This paper introduces a method for accruing data for military troops operating in tactical level in a battlespace, namely, Sensor Element Munitions (SEMs) with encased Sensor Elements (SEs) . The objective of the introduced idea is to foster the means and technologies which increase the possibilities to facilitate collecting data for an improved Common Operational Picture (COP) utilizable in tactical operations. This rapidly deployable reconnaissance element, SEMs, is introduced as a tool for a comprehensive approach to perimeter control and intelligence, surveillance and data gathering in tactical level operations. This paper discusses how to utilize SEMs in military operations carried out in versatile battlespaces. Finally, the significance of the concept of Situational Awareness (SA) beyond the Event Horizon is discussed in relation to mission success in tactical level operations.

This paper tackles the following three research questions: 1) How to allow rapid collecting of data beyond the event horizon necessary for tactical troops with the assistance of Sensor Element Munitions? 2) What is the composition of SEMs? And lastly, 3) How to forward these gathered data to the given troops rapidly and reliably?

In particular in low-level operations, namely, those of a company and battalion, military commanders must be able to maintain an optimal COP facilitated by an equally optimal overall SA. Some of the practical data gathering means enabling fulfilling these data requirements involve issues such as Blue Force Tracking (BFT), Target Identification (TID) and Combat Identification (CID) as discussed in [1]. The term CID can be defined as a process of attaining an accurate and timely characterization of detected objects in the joint battle space to the extent that high confidence, timely application of military options and weapon resources can occur [2]. The collected data can thus be forwarded by using available existing network systems to a given entity. A definition for SA applicable is verbalized in the Army Field Manual 1-02 (September 2004): “Knowledge and understanding of the current situation which promotes timely, relevant and accurate assessment of friendly, competitive and other operations within the battle space in order to facilitate decision making. An informational perspective and skill that fosters an ability to determine quickly the context and relevance of events that is unfolding.” Now, to improve SA to ensure mission success, tools and concepts applied in Net Centric Warfare (NCW) environments can be utilized. The end-state aims at merging the data collected from a finite array of sensors and sources. SA comprises three levels: 1) perception, 2) comprehension and 3) projection [3]. Operationally, SA, or lack of it, remains a key factor in military operations and intelligence capabilities [3], [4]. SA is linked to Dismounted Battle Command System (DBCS) [5] and to Blue Force Tracking.

For the purposes of this paper, the term Event Horizon is used to denote the level which transcends the level of traditional reconnaissance capabilities of low-level military commanders. This is, commanders in battalion and company levels in militaries of small countries lack the capability of exploiting reconnaissance tools, such as Unmanned Aerial Vehicles (UAVs) and satellite services. Therefore, it is essential to introduce quickly deployable means to gather intelligence data, the means and tools that do not require procuring new types of weapons or materiel to overburden the organization in question.

Data beyond the Event Horizon refers to data collected beyond the visual horizon. In case of troops and operations concerning the battalion and lower levels, this collecting of data beyond the visual horizon is impossible because of the lacking reconnaissance tools described above. The pace of warfare is hectic in these low-level operations with multiple encounters in a tight time-frame. Thus more precise data are required for improved SA to ensure effective and timely decision making. This involves accounting for the phenomena taking place in the electromagnetic spectrum based on these observations and, moreover, the accrued data have to be in operational use in a matter of minutes. Indications of shots, explosions and acoustic and visual signatures of vehicles and their locations and actions are needed to create a Common Operational Picture (COP).

Typically, a COP comprises three types of modules: 1) information gathering sources that observe events and report information to the command and control module, 2) a command and control module that makes decisions based on both information received directly from its information gathering sources and information reported by other peers, and 3) display units at the emergency location that receive instructions from the command and control module [4].

The core capability in an optimal SA is a COP that fosters effective decision making, rapid staff actions, and appropriate mission execution [4]. The COP is employed to collect, share and display multi-dimensional information to facilitate collaborative planning and responding to security incidents.

This paper discusses recent research in regard to possibilities for increasing SA to ensure mission success in low-level military operations in battlespace. The remaining of the paper is arranged as follows: Section II introduces related work, Section III describes the composition and characteristics of SEMs and their utilization, Section IV explains the characteristics of SEMs together with the communication process, Section V concentrates on the targeting process, Section VI deals with the possibilities to analyze the collected data with Section VIII concluding the paper.

II. RELATED WORK

This paper is linked to three major areas researched by armed forces. Firstly, the key issue concerning military troops is their efficiency, which can be gained via an improved operational setting involving optimal SA, BFT and Command, Control, Computers, Communication, Information and Intelligence, (C^4I^2) [6]. Secondly, efficiency in military operations asks for optimized target identification, gained via utilizing the electro magnetic spectrum [7]. Thirdly, performance in low-level operations is currently being extensively examined, especially in conscript-based armed forces

In low-level operations, only minimal time is allocated for gaining SA data or waiting for orders. Systems applied in this level have to be simple, easy to use, and rapidly deployable. An example of this type of an operation is a dismounted company attack, where the structure of an attack process can be seen as a chain of planned events. This process requires particular services, which can be allocated to the requester of a service only if the service is available and within reach. The overall process of a company attack is explained in Figure 1.

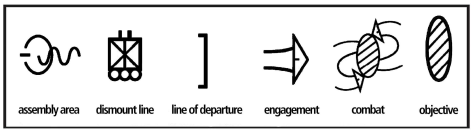

Figure 1. Company attack as a process.

Secondly, as militaries search for effective, rapid and reliable means to collect and analyze SA data in the battlespace, the realm of Wireless Sensor Networks (WSNs) [8] is relevant. As noted, WSN can be quickly-deployed, suitable for unattended monitoring and unnoticeable, representing an ideal choice for military applications [8]. For this particular purpose, remote, ground-based electronic sensors, used to collect intelligence on enemy movements and manoeuvres have been available for decades [9]. Yet, the reconnaissance and beneficial utilization of various types of sensors and sensor networks continue to be applicable. By adopting suitable sensors for appropriate platforms, the critical data can be gathered from the battlespace early enough to foster executing versatile military operations. Improved SA remains a key issue for small units operating in versatile military operations in a given battlespace and thus new and rapid means to collect data continue to remain necessary. For instance, the Finnish Defence Forces is developing its own sensors for improved skills in surveillance and intrusion detection systems to replace the anti-personnel land mines.

Obviously, all armed forces look for enhancing the performance and agility of their troops. This paper discusses a solution, the Sensor Element Munitions (SEMs) that can be produced by utilizing existing COTS-technology. The sensing elements of SEMs represent inexpensive, rapidly deployable means and draw from COTS-products to facilitate data accruing behind the event horizon.

III. THE SET-UP AND UTILIZATION OF SENSOR ELEMENT MUNITIONS

The data collecting and reconnaissance carried out by means of SEMs take after the standard High Explosive ammunition used in mortars and howitzers. The main difference is in the payload, in which the explosive charge has been replaced with a parachuted Sensor Element (SE). This SE is strong enough to withstand the forces of acceleration of a regular munition. The munition is delivered to a hostile area with similar procedures as standard High Explosive munition. The SE acting as a payload will be exhausted from the ammunition shell while airborne.

Structurally, the SE comprises a power source, an array of sensors, a transmitting unit and a relay-unit. The SE can act simultaneously in two roles: in accruing data and in a relaying role between two SEs. The SE does not receive data, but only transmits the data gathered, including GPS-data of its own position. The SE comprises sensors such as a visual sensor applicable to monitor targets both in daylight and low-light conditions as well as in the darkness. The central sensor is forward-looking infrared (FLIR) which is an important sensor for its advantages in night vision in securing military camps, reassuring soldier security, and detecting suspected terror activities in the battlespace [10].

The SE carries an image intensifier element and low-light sensors. It also features shortwave infrared (SWIR) and longwave infrared (LWIR). In addition, the SE includes detection elements for sensing acoustic, seismic and magnetic interference. Moreover, the sensor package features detection elements capable of detecting infrared and the movement of an individual and a wheeled or tracked vehicle.

Once the SE has been ejected out of the munition, it immediately starts to gather and transmit information from its area to own troops in an Ultra-Wideband using the frequency of 2,4 GHz for securing the transmission QoS. Another suitable method for transmitting the data is Worldwide Interoperability for Microwave Access (WiMAX), which is based on IEEE 802.16 standard utilizing frequencies of 4,4 -5,0 GHz.

The WiMAX standard 802.16d is applicable for slowly moving users whereas 802.16e is tailored for mobile users [11] and therefore we concentrate on Portable (Mobile) WiMAX, 802.16e, the channel sizes of which are 5 MHz, 8.75 MHz and 10 MHz. The usable WiMAX, 802.16e is based on orthogonal frequency division multiplexing (OFDM), orthogonal frequency division multiple access (OFDMA) [12]. In short, WiMAX combines OFDMA, an advanced multiple-input multiple-output (MIMO) as well as beamforming (BF) features [13]. These features together offer flexible bandwidth and fast link adaptation, creating a highly efficient air interface exceeding the capacity of existing 3G radio access networks [13]. These systems are suitable for military surveillance applications.

In low-level operations in the battlespace, data collecting can be facilitated by SEMs. The shell of SEMs can be manufactured of either steel, composite, or heat-treated plastics. SEMs can be deployed to a target area either by a howitzer or a mortar. In what follows, we take a closer look at SEMs and examine the processes of munition deployment, data collecting and data distribution.

Firstly, the ammunition shell of SEMs can be manufactured of various materials. One of these is composite, originally tailored for ballistic protection. The benefits of this material are its strength and suitability for munition core material in that it is lighter than steel and easily forged into the desired shape and structure. When munition is lighter, the payload can be heavier, if desired. Light-weight munition can be deployed further behind enemy lines by using the same charge as in steel munition. Moreover, composite represents a material, which can be surfaced with materials capable of absorbing radar beams, making the SEM less visible in enemy counter-artillery radars. This means that SEMs and the SEs are invisible on the screens of an adversary's counter-artillery radars while SEMs are being deployed to enemy territory by air. Furthermore, as the SE is made of composite, when it hovers in the air above an adversary, the SE manufactured of composite is less visible compared to an SE made of traditional steel. In short, an adversary receives no early warning of the incoming munition and is unlikely to be capable of locating either the positions of an artillery weapon or the howering elements early enough. Therefore, it is highly unlikely that any counter measures be executed for there are no indications of any oncoming actions whatsoever. Figure 2 illustrates the structures of various types of SEMs with the encased SEs.

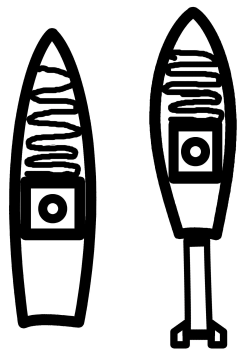

Figure 2. Structures of Sensor Element Munitions: An artillery SEM (left), a mortar SEM (right). Artillery and mortar shells can be manufactured of various materials. Composite-manufactured Sensor Elements (SEs) are packed inside the munitions together with their parachutes.

Secondly, the tactical use of the SEM-based reconnaissance system is as follows: 1) When reconnaissance data beyond the Event Horizon are needed, a commander issues the order to deploy the munition to the target area, 2) mortars or/and howitzers perform the tasks to the designated areas, 3) the SE transmits the data to own receivers, 4) resulting improved SA is utilized in commanding troops and shooters to the designated areas or targets to maximize the performance of own troops (and gain the initiative). If more data are wanted, the described phase two can be repeated and more data can be gathered. This process is explained in Figure 3.

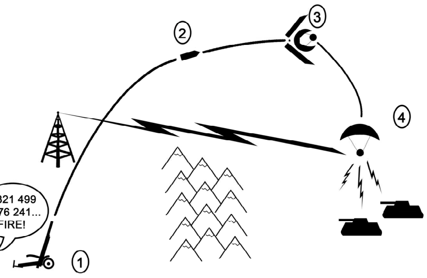

Figure 3. On deploying an SE above an enemy territory: 1) Fire Support Order is issued, 2) the SEM is airborne, 3) the SEM opens and ejects the SE, 4) the SE starts to transmit gathered data from the enemy territory and targets.

Once the critical data have been collected they have to be quickly analyzed to be used for evaluating different Courses of Action (COAs). Success depends on an accurate mission analysis and a timely evaluation process of the accrued data. Improved SA results in optimal time for mission execution and simultaneous minimizing of casualties, which increases efficiency and leads to minimum recovery times improving the overall efficiency and performance capabilities of the troops utilized.

Once commanders have access to more current reconnaissance data for mission execution, they are able to analyze different COAs and calculate the pros and cons to evaluate the best possible method to operate in any scenario prevailing. As explained in Figure 4, military commanders have by default value at least two different options for executing the mission in question. Having completed Military Decision Making Process (MDMP), the most effective operation can be executed to maximize the performance of the designated troops. In the described scenario below, the commander focuses the performance on incapacitating the Command Post (CP), the alternative number 2, instead of attacking against the armored enemy.

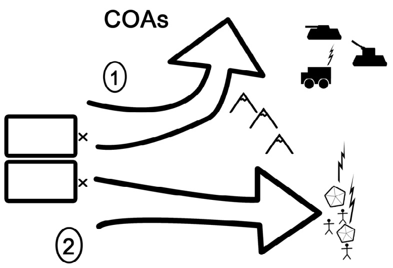

Figure 4. Possibilities of COAs.

Figure 5 explains the basic process of data gathering beyond the Event Horizon, especially in operations suitable for low-level troops. The deployed and hovering sensor element acts like loitering munition, sensing and measuring the prevailing electromagnetic spectrum, collecting and transmitting data to the receiver-station. An antenna can be installed both in a fighting vehicle and on the ground, depending on the prevailing combat-situation.

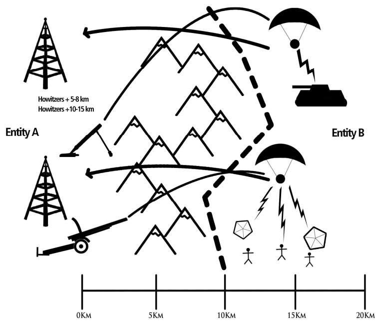

Figure 5. The data gathering process for improved SA beyond the Event Horizon and the transmitting of these data to own troops.

Time itself is a critical resource in this type of reconnaissance process. In order to avoid wasting time, the signals and data must be transmitted reliably from the SE to the receiver-station. For this purpose, the SE utilizes smart antenna technology meaning that antenna transmission and propagation pattern can be optimized for the optimal outcome. The accrued data can be transmitted reliably to the receiver, and because of the clear Line-Of-Sight (LOS), there is only a limited number of obstacles or attenuation disturbing the coded transmission process from the sensor to the receiver-station. This method is described in Figure 6.

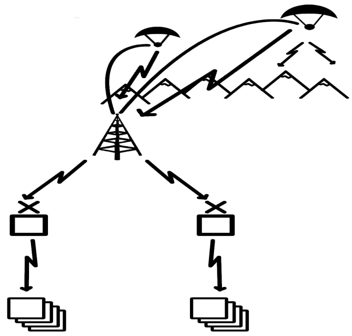

Figure 6. A method for transmitting the accrued data to the commanded troops to ensure successful operations.

IV. On Airborne sensors, SEMs and Communication

In any military operation, airborne sensors are important for missions, such as force protection, perimeter control and intelligence utilization [9]. Transmitting the accrued data to prevent fratricide and ensure success in operations presupposes optimal communications. WiMAX transmission offers applicable possibilities in forwarding collected data. The distances in the transmission process are relatively short, ranging from 1 kilometer to 20 kilometres in conditions of clear Line-Of-Sight.

The sensor package inside SEMs, namely the SE, can be made of existing COTS-products comprising sensors capable of sensing most of the phenomena occurring in the electromagnetic spectrum. In general, COTS-products are relatively inexpensive and reliable in terms of function, as explained in [14]. An SE of a SEM comprises the following sensors: acoustic-, seismic-, magnetic-, visible image-, shortwave infrared (SWIR)-, thermal-, infrared-, low-light television (LLTV)-, and sensors for laser tracking and spotting and sensors for facial recognition. In terms of automatized identification and verification, a facial Recognition System represents a computer application capable of automatically identifying or verifying a person from a digital image. One possibility is to compare selected facial features from the captured image with an existing facial database.

The analyzing centre has the capability for the fusion of all the accrued sensor information. The sensor package comprises a short lifetime battery, which can produce energy for the sensor package for the duration of 4 – 6 minutes (howering time). The battery can be equipped with capacitors or electric double-layer capacitors (EDLC) if the required energy level is inadequate with the selected sensor package.

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Once an SE is airborne, it immediately starts to transmit the gathered data to own troops either directly or, if the transmission distance exceeds the capability of the transmission unit, the SE transmits the data to another airborne device, which acts as a relay station in relation to own troops. The SE communicates with the receiver station and other sensor element packages over a 2,4 GHz Ultra-Wideband Network system. The accrued data are crypted for security reasons.

V. Comprehensive Targeting Process

The cycle of a complete targeting process can be described as Detect, Identify, Decide; Engage and Assess (DIDEA) [4]. The cycle is outlined in Figure 7 below. The DIDEA provides an iterative, standardised and systematic approach supporting targeting and decision making, being generic enough to be used as a systematic process for C2 node targeting and decision making. This process is thoroughly discussed in [4].

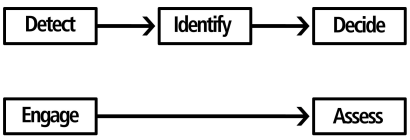

Figure 7. The simplified DIDEA process.

The decision as to whether or not to open fire is based on the visual signature of a given uniform, weapon and gear as well as magnetic, seismic or acoustic signals identified by a sensor [9]. Self-evidently, the transmission of combat-critical location and identification data play a crucial role in the battle space. After the accrued data have been transmitted and received, they flow through a dissemination process, where these data are analyzed and fused to form a COP and to increase the overall SA. Figure 8 explains the process of Signature Prediction Process (SPP). As described in Figure 8, sensors accrue data and transmit these data for analyzing centers. The data collected with SEMs are verified with the data gathered with other sensors to in order to predict and anticipate the type of target and its actions.

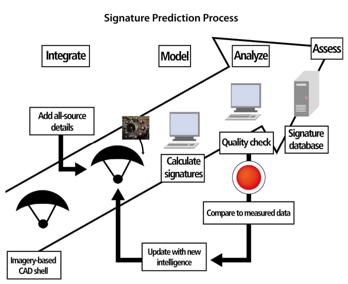

Figure 8. The Signature Prediction Process, typical of several surveillance and detection systems.

The destruction power of a given weapon system has to be optimized to account for the enemy location (forest, open area, Urban Territory), the state of movement on-the Move (OTM) or at-the-halt (ATH), and the protection-level (mounted, dismounted, dug).

The cruel reality remains that an executive commander is necessarily aware of fact the there is always the possibility of fratricide and collateral damage. Figure 9 emphasizes the importance of accurate and timely SA around the target area. The shooter has to be aware of the locations and status of both own troops and the enemy. It is critical to optimize the destruction power of a weapon system along the identification of a target. When the target represents a hierarchically critical enemy commander, he or she can be incapacitated by transmitting the coordinates and visual signature to the designated shooter, as indicated in Figure 9.

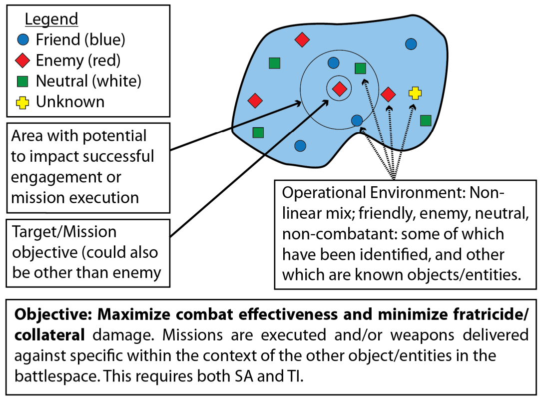

Figure 9. The importance of accurate and timely SA around the target area.

If the commander has Close-Air Support (CAS) available, he or she can utilize the performance of the data analyzing centre (indicated as a satellite dish in Figure 10), the collected data can be forwarded directly to the shooter. This process improves the overall performance and saves time and utilizes the performance of a designated fighter (cf. Figure 10 below). As for the receiving antenna constellations, they can be both ground- and vehicle-born systems.

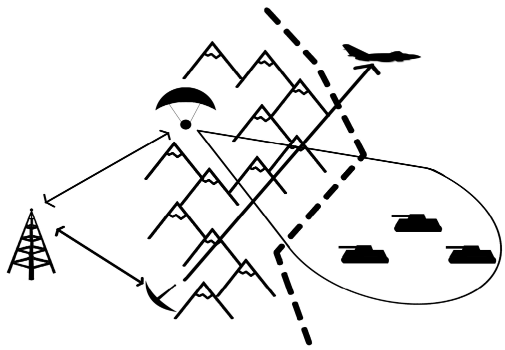

Figure 10. The process of detecting enemy forces and forwarding the accrued data to an Analyzing Center and finally to the shooter.

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In a critical case when the target is a very important human being, he or she can be incapacitated by transmitting the required precise data of the target and its location to the sniper or to a team of snipers. A cellular telephone can act as a receiver. The figure caption of a sniper's cellular phone is depicted in Figure 11.

Figure 11. Adequate target identification data transmitted to an individual member of Special Forces for eliminating purposes.

VI. Means to Analyze Collected Data

When it comes to transmitting data, the following issues have been identified. As tested in [13], an 802.16e WiMAX Testbed has provided throughputs of 5.75 Mbps Upstream with a modulation and coding of 64 QAM ¾ [13]. These amounts of data seem adequate to receive all the required sensor data.

With the assistance of automated targeting programs and classifiers, it is possible to recognize faces, find hidden and concealed targets, and look for essential information by means of computation algorithms [15]. Classifiers, such as a Support Vector Machine (SVM), K-Nearest Neighbourhood classifier (KNN), and BP neural classifier, can be utilized in battlefield target identification [7]. The recognition of an end-user can be based on visual biometrics and the most conventional identification, the computer-assisted recognition of human face [16]. The ubiquitous networks and sensor data can act as assisting tools in detection, recognition and especially in target classification [15]. Moreover, the data produced by various multi-sensors can be utilized in the data refinery process to ease the recognition and identification process with the assistance of data fusion processes by resorting to computer-programs designed for data fusion processes [17]. In fact, when using the K-Nearest-Neighbour (KNN) algorithm, approximately 80 % of unknown target samples can be recognized correctly, when the known target classification accuracy remains above 95 %. This enables the use of the ATR and the Automatic Target Cuer (ATC). Face recognition schemes that combine wavelet transform, SVM and clustering can be exploited identifying human beings [18].

As for object categorization, high-definition closed-circuit television (CCTV) cameras feature many computer controlled technologies that allow them to identify, track, and categorize objects in their field of view. As defined in [19], WiMAX mobile technology is a good candidate in supporting the CCTV applications in the context of mobile users. Furthermore, Video Content Analysis (VCA) represents the capability of automatically analyzing a video to detect and determine temporal events not based on a single image. Moreover, a system utilizing a VCA can recognize changes in the environment and identify and compare objects in the database using size, speed, and color. Also, VCA analytics can be used to detect unusual patterns in a video's environment. The system can be set to detect anomalies in a crowd of people and a VCA also has the ability to track people on a map by calculating their position from the images.

VII. Conlusions

This paper has introduced a robust SEMs-based data collecting means for gathering data beyond the Event Horizon. This approach draws from the utilization of existing sensors and WiMAX technology. The composition and functionality of SEMs have been introduced. The results of this paper offer a method to improve SA, COP, CID, and TID. The concepts of SEM and SE have been introduced in Figures 2 – 3. The introduced solution is applicable in increasing the performance capabilities of modern troops.

Three research questions were raised in Section I, and the answers to questions 1 and 2 were provided in Section III with visualizations in Figures 2 and 3, and question 3 was addressed in Section III with visualizations in Figures 5 and 6.

As evident, in all operations and in low-level tactical operations in particular, critical Situational Awareness data have to be collected rapidly, since mission success is time-dependent. Figures 4 – 6 concentrated on describing the data accruing process and utilization of data in military operations. Once data have been collected, a battle can be won only by careful mission planning, comparing different COAs and rapidly executing successful operations. Figures 7 – 9 illustrated the process of targeting. Thereby the adoption of existing COTS-technologies, when appropriately applied, offers a key to ensuring the desired success.

Operational time spent in the battlespace can be minimized by careful mission analysis and thorough evaluation of Courses of Actions (COAs). Critical data have to be forwarded to shooters, as illustrated in Figures 10 – 11.

So far, all the decision-making processes in battlespace settings have culminated in a human being making the final decision to apply performance in missions. In the future, this decision maker's position may be manned by Artificial Intelligence (AI). AI can be benefitted as an assisting power of a commander to ensure mission success. Figure 12 describes this process in brief.

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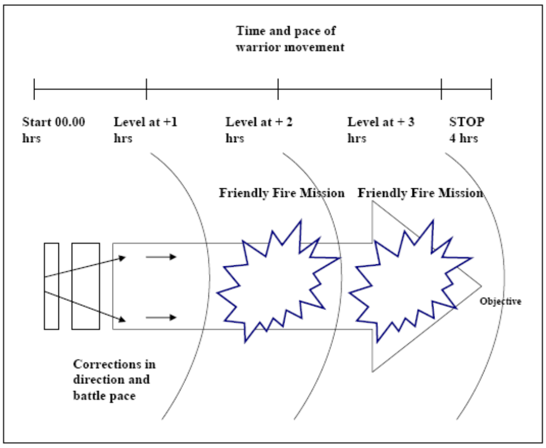

Figure 12. Once COP and SA have been fused, a computer can assist in fostering the movement of own troops along the pace and direction.

This mid-term solution remains applicable until the current armed forces are being replaced by robotic militaries of the future. Before this, however, humans have to continue coping with their own intelligence assisted with optimal data accruing and analyzing tools in order to be able to make judgements that keep incorporating both the probability of success and affordable costs.

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