A Survey of Military Applications of Wireless Sensor Networks

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Abstract— **This paper presents an overview of defense related applications of wireless sensor networks (WSNs). The operational context of modern military engagement has diversified into four scenarios, which set requirements and constraints upon applications of WSNs. The sensor types and their capabilities determine and constrain the application of WSNs. We classify military applications of WSNs according to operation scenarios and sensor types, and describe key classes. We also discuss research and engineering issues for future generations of military WSN applications.**

Keywords-wireless sensor networks; battlefield; urban; other-than-war; force protection; presence; CBRNE; ranging; imaging

I. INTRODUCTION

Communications is present in almost all aspects of military operations [1]. It is important in the distribution of commands and ensures distribution of logistical information, intelligence and data from sensors. In this work, we survey military applications based on collecting data from sensors by use of wireless sensor networks (WSNs).

Military communications, by any means, must be maintained in the area and time where needed [1]. In general, they should be resistant to jamming, direction finding and other electronic warfare threats, and provide end-to-end message security. This also holds for military WSN communications.

In a common battlefield scenario of military engagement there is a well-known and well-defined enemy, in the air, on land or at sea. However, recent experience has revealed more scenarios, such as truly worldwide operations, operations in urban environment, and operations other than war (OTW) e.g. peacekeeping and disaster relief [1]. We consider applications of WSNs in a large area battlefield (but not worldwide), urban warfare, OTW and force protection. The latter intersects with the first three scenarios. Its requirements are discussed in [2].

The capabilities of military WSN applications depend not only on wireless communications fulfilling the requirements mentioned above, but also on the capabilities of sensors. The sensors measure various physical phenomena. Some of the most important in military applications are electromagnetic waves, light, pressure and sound, which result from gunfire and explosions. Sensors can detect and possibly measure chemical, biological and explosive vapor, as well as presence of people or objects. We will use the sensor capabilities as one of key determinants of the type of military application of WSNs.

Irrespective of the scenario and the sensor type, the WSNs are mostly useful in providing a cost-effective method of gathering information about the environment, and actors in that environment [1]. In the cases of battlefield, urban warfare and force protection, the use of WSNs can reduce the uncertainty over where the enemy forces will be deployed or what role they will be fulfilling. In OTW scenarios, the use of WSNs can reduce uncertainty over where the population which needs to be protected is, and which areas are at risk of natural disaster.

The data measured by sensors is sent from the sensor nodes to one or more gateways, after possible pre-processing. The gateways can provide data fusion, additional data processing, and the reach-back capability [2]: near real time connection via longer range wireless transmissions or satellite links; and asynchronous data transfer to passing unmanned aerial vehicles.

A tiered WSN architecture for military surveillance applications is proposed in [3]. The hierarchical architecture is built using sensor nodes with short-range radio and wireless gateways with wireless long-haul connectivity. This architecture affords greater agility and expandability, with possible operations from a small-scale single cluster of sensor nodes to many chained connections spanning a large area [3].

The communication architectures influence the coverage and connectivity of WSNs, which in turn set the performance and limitations of military applications of WSNs. A survey of coverage in WSNs and related issues is provided in [4].

The rest of the paper is structured as follows. Section II. presents a classification of military applications of WSNs. Section III. describes the main classes identified in Section II. Section IV. presents a discussion of research and engineering challenges in military applications of WSNs. Section V. concludes the paper.

II. Classification of Military Applications of WSN

A. Types of Military Operations

In modern military operations, we can distinguish four scenarios: battlefield, urban warfare, other-than-war, and force protection. These scenarios define the size and type of environments, which in turn define the size and requirements for WSNs. Battlefield: large-scale, non-manually deployed WSNs. Urban warfare and force protection: medium-scale (up to several 100s of nodes), manually deployed. Other-than-war: any scale, both manually and non-manually deployed.

B. Sensor Types

Functional requirements for urban warfare as well as for other military operational contexts point to the use of the following sensor types [5]:

• Presence/Intrusion (e.g., based on a combination of infrared, photoelectric, laser, acoustic, vibration, etc.);

• Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) and Toxic Industrial Material (TIM) detectors.

• Ranging (e.g., RADAR, LIDAR, ultrasonic, etc.);

• Imaging (including infrared and LADAR imaging);

• Noise (acoustic sensor able to produce an audio stream).

C. Soldier-worn WSNs

A particular case of WSN military applications is the soldier-worn sensor nodes [6, 7]. This application aims to track vital functions of a soldier and detect states of serious distress or risks of fatality. As such, it will be considered as belonging to force protection scenario. This application can be used in OTW scenarios as well, such as in tracking the vital parameters of fire-fighters or other personnel participating in high-risk (e.g. rescue) operations.

D. Classes of Military WSN Applications

An overview of military sensing technologies is provided in [8], and we include some of them, which are suitable for use with WSNs. In the Table I., the classes are identified by acronyms defined in Section III.

TABLE I. Classes of Military WSN Applications

Sensor types	**Operation scenario**			
	Battlefield	***Urban***	***OTW***	***Force protection***
Presence/ Intrusion	SHLM, AAP	SDT		SHLM, AAP, SDT
CBRNE	RCS		VDM	VDM, RCS
Ranging		EARS, INS	BL, INS	EARS, BL, SDL, PP
Imaging	ASW	SDL, MCM		SDL, MCM, PP
Noise		ATS	ATS	ATS

III. Description of Classes of Military WSN Applications

Self-healing land mines (SHLM): A network which supported an autonomic system of antitank landmines is described in [9]. Each antitank mine monitors its neighbor's state, senses threats to itself, and responds autonomously to those threats by moving. Sensing is based on a distributed self-contained acoustic location system and accelerometer sensors. Roadmap for development of the next generation SHLM system was provided in [10].

Aerostat acoustic payload for transient detection (AAP): Acoustic sensor arrays suspended below tethered aerostats are used to detect and localize transient signals from mortars, artillery and small arms fire. The airborne acoustic sensor array calculates an azimuth and elevation to the originating transient, and immediately cues a collocated imager. Unattended ground sensor (UGS) systems can augment aerostat arrays by providing additional solution vectors from several ground-based acoustic arrays to perform a 3D triangulation on a source location [11]. A new generation of acoustic vector sensors measures the pressure and the particle velocity in all three directions, so the source direction is measured directly [12].

Soldier detection and tracking (SDT): In protecting military sites or buildings, unattended acoustic and seismic sensors are envisaged to survey specific points by the detection of individual enemy soldiers approaching [13]. An application for human tracking uses a mixture of acoustic sensors and daylight still cameras. The close integration between the acoustic and visual modalities resulted in the camera activation at the proper time and location only. The network transmits only those images which are consistent with the acoustically generated tracks, providing a very high hit rate [14].

Low-cost acoustic sensors for littoral anti-submarine warfare (ASW): The ASW concept utilizes small sensors with passive and active sonar to detect modern diesel submarines operating on batteries. The sensors can be deployed in large numbers (hundreds or thousands) to provide a high density sensor field. The low cost sensors have a short detection range and therefore are far less susceptible to multipath reverberations and other acoustic artifacts [15].

Early attack reaction sensor (EARS) - a man-wearable gunshot: The EARS is a passive acoustic sensing system that detects gunshots (muzzle blast and/or shockwave) to provide relative azimuth and range information of the shot origin to the user. The EARS system senses with a small microphone array. It has been tested in both open field and military operations in urban terrain (MOUT) environment and has provided useable bearing and range information against the firing positions [16].

Sniper detection and localization (SDL): To improve the soldier's protection against snipers, acoustic localization of shots is performed. Mobile antennas can be mounted on the soldier's helmet. To 'identify snipers' in an operational area before troupes are deployed - two acoustic arrays and a day-night video camera are used. If the resources are placed in correct locations, two acoustic arrays could provide direction of the shooter and a possible location by triangulating acoustic data whereas the day-night camera could produce an affirmative image of the perpetrators [12, 17, 18].

Time difference of arrival blast localization using a network of disposable sensors (BL): Using a mesh network of inexpensive acoustic sensors, the system performs a three-dimensional, Time-difference-of-arrival (TDOA) localization of blasts of various yields in several different environments. The system is able to perform accurately in the presence of various sources of error. Once deployed and activated, each sensor node self-configures into an ad-hoc, multi-hop, robust WSN connected to one or more gateway nodes [19].

Perimeter protection (PP): Widely-used concepts of perimeter protection with zone sensors will be replaced in the near future with multi-sensor systems. This kind of systems can utilize day/night cameras, IR uncooled thermal cameras as well as millimeter-wave radars detecting radiation reflected from target. Besides the sensors, the most important elements that influence the system effectiveness is intelligent data analysis and a proper data fusion algorithm. A similar system of ad-hoc WSN is designed for border surveillance [20, 21].

Chemical, biological, and explosive vapor detection with micro cantilever array sensors (VDM): A micro cantilever-based Self-Sensing Array (SSA) technology to measure trace concentrations of explosives, toxic chemicals, and biological agent signatures is proposed. The prototype system employs a variety of sensor coatings and the ability to analyze electrical and thermal properties of vapor molecules on the cantilevers [22].

A low-cost remote chemical sensor for E-UAV platforms (RCS): A low-cost sensor for the detection of hazardous chemicals was developed for deployment on expendable unmanned aerial vehicles. The sensor was designed to detect chemical vapors in a nadir-viewing configuration from an altitude of 300m while traveling at an air speed of 96km/h. Hazardous chemicals are detected and identified by their unique infrared absorption signatures. To reduce false alarms resulting from scene variations, 3 color filtered photo-diode detectors were integrated with the sensor. The photo-diode detectors view the same scene as the infrared detectors and provide the additional scene information required to discriminate terrain variations from chemical emissions [23].

Novel optical sensor system for missile canisters continuous monitoring (MCM): Missile environmental monitoring dramatically increases missile active service life, saving millions of dollars and reducing the number of missiles needed. This requires a high-speed continuous monitoring sensor system that collects and stores data on environmental shock and vibration (up to 100 g) in missile canisters without electrical hazards. An optical sensor system capable to monitor shock and vibration in missile canisters in three dimensions at high speed (5 kHz) is proposed. The system is planned to be used in environmental exposure monitoring system to collect and store vibration, shock, temperature, or damaging events data over the entire lifetime of a missile canister [24].

Inertial Navigation System (INS): Time difference of arrival (TDoA) measurements from a WSN are used to aid a low-cost INS. The use of magnetometer data in addition to the WSN for INS aiding is introduced. Magnetometer data provides direct information of the vehicles heading and pitch regardless of vehicle's true orientation and consequently improves orientation estimation [25].

Acoustic threatening sound recognition system (ATS): Threatening sound detection, classification and localization can be effectively used in asymmetric warfare and against terrorist threats. Recently, significant research efforts have been made in this area using WSNs. A novel acoustic threat recognition system with a distributed and hierarchical architecture is proposed. The proposed architecture allows cooperation among sensing nodes to collaboratively detect target signatures, reduce false alarms, classify target types, and estimate the acoustic source location. Its advantages include energy efficiency, reliable detection and classification, low detection and classification latency, and reduced false alarms [26].

IV. Research and Engineering Challenges

The development of low-cost sensors is driving research into arbitrary array formation (sensor and communications) and associated resource management to maximize power/energy, bandwidth and sensing capabilities [1].

A. Requirements for Future Military-use WSNs

The requirements for military applications of WSNs in the present and future 3-4 years, and realistic assumptions are discussed in [2]. The physical size and weight need not be a major constraint. Sensor nodes must be able to rapidly identify neighbors and configure themselves, similar to *ad-hoc networks*. It is assumed that most of the networks will remain reasonably static. For the majority of operations the area to be covered may be from 5 to 20 km^2. Communication range of a node should be 250-500m, and sometimes greater than 1km. Thus, the number of nodes will rarely exceed 100, but the number and density of nodes are likely to significantly grow in the next 5-10 years. Communication between nodes and gateway(s) will be two-way, but likely remain dominated by node-to-gateway flow. The nodes should be covert with a small electromagnetic emission pattern. Data rates may remain low to medium. The reliability of communication, resistance to jamming and interception, and temper-proof communications are of vital importance. In addition, the WSNs should be resistant to the loss of certain number of individual nodes. Such networks are known as d*isruption-tolerant networks*.

B. Engineering Challenges

Overcoming the following engineering challenges can greatly improve capabilities of the WSNs in military applications [2]: identification of several simultaneous events and reliable correlation of information from neighboring nodes; classification of objects and events in addition to detection; improved integration of different types of sensors; mini-aturization and better robustness of sensors; common formats and standards for sensor data and communications [27, 28].

C. *Research Challenges*

The research is required to increase the usability, flexibility and security of the WSNs [2]. Security issues are related to reputation approaches to protect against spoof messages or jamming. Suitable power supplies, energy harvesting, and energy-efficient protocols are required for better endurance of WSNs. Effective and efficient remote air delivery of sensors improves coverage of the monitored area.

Improvements of communication architectures are possible. In particular, a two-tiered architecture with gateways as hubs and sensor nodes as spokes yields better flexibility and agility than homogeneous (one-tier) WSN [3].

An important research topic is *coverage* in WSNs. It combines the sensing range of sensors and communication range of radios on the sensor nodes [4].

Last, but not the least, the *information processing, fusion, and knowledge generation* are research topics that can significantly enhance the capabilities of military applications of WSNs [14, 17]. They are related to coverage because of the need to have reliable correlation of information across space and time to perform data mining in particular, and knowledge engineering in general.

V. Conclusion

The new operational contexts of military engagement have opened door for various applications of WSNs. The capability of a WSN military application depends on the type and capabilities of sensors, wireless communications architecture, coverage, and appropriate information processing, fusion and knowlerdge generation. We have presented a classification of WSN military applications according to the operation scenario and sensor type. We provided a survey of the WSN application classes and considered research and engineering challenges for the next generation of WSNs in military applications.

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