Abstract
Recent developments in emerging sensor and communication systems technology are presented with a focus on the special needs of urban warfare. The paper also offers an overview of future requirements for the processing and sensor support needed to realize these novel system concepts.

1. INTRODUCTION
This paper presents advanced ad-hoc networking concepts with sensor systems that exploit the unique potential of time-based radar processing, passive W-band radiometer technology for concealed weapon detection, and advanced agent based technology for knowledge sharing across sensor networks. Finally, the paper offers an overview of future requirements for the hardware and sensor support needed to realize these novel system concepts.

2. BACKGROUND
The focus of this paper is on the challenges posed to systems development to support the warfighters in Urban Warfare and in Homeland Security Groups. Urban environments provide challenging conditions in which unit forces must operate to detect and neutralize asymmetrical threats. A challenging aspect of this environment is the close proximity among friendlies, neutrals and hostiles. The Urban Warfare challenges are:

- Robust communication in networks
- Use and coordination of unmanned vehicles to do Situation Awareness
- Detecting concealed weapons on citizens and intruders
- Detecting snipers/threats using concepts of ad-hoc networks of multiple sensors.

The most challenging technological issues for the system integrator is to create a solution that provides an architecture for improved communications, improved detection/localization and improved network operation. The Urban Warfare challenge is to combined emerging technologies in a system that improves the survivability and probability of disabling the threat.

Advances in beyond line of sight (BLOS) and through wall sensing technologies are needed to quickly detect and identify hostile elements so the appropriate response can minimize casualties and collateral damage. The unit soldier needs a clear tactical picture of the entire situation to respond appropriately. As a result, fully networked communication capabilities must be shared among the units so a total and more accurate tactical picture can be determined.

Advances in communications technologies are needed as current systems experience severe fading in the difficult multipath conditions typically encountered during Military Operation in Urban Terrain (MOUT). The recent development in advanced RF technologies combined with the maturation process of emerging systems concepts for future of urban warfare applications has led us to investigate new combinations of advanced ad-hoc networking to achieve unique sensor systems designs.

The analysis of the specific requirements imposed by the harsh urban warfare environment points towards networked-based sensing/comms systems solutions. This approach fully exploits the unique potentials of time-based RF systems (wideband and ultra-wideband). The following examples in this paper describe emerging radar and communications system technologies and concepts that will support the urban warfare fighter of the 21st Century. Many of these technologies are being researched by DARPA, CECOM and AFRL.

3. EXAMPLES OF CURRENT SYSTEMS DEVELOPMENT

3.1 The XNET
Developed at Lockheed Martin Advanced Technology Laboratories (LM ATL), the eXtreme NETwork (XNET) concept is based on the use of networked sensors across a platoon and provides innovative solutions for this new mode of operation. The concept leverages the advantages of both spatial and spectral diversity offered by the deployment of small special forces units or special weapons and tactics teams equipped with radios that have very wide bandwidths. The soldiers in the squad form an ad-hoc network of sensors/hopping nodes used for improving both sensor and communication performance of the squad.

Synchronized wideband communications offer unique locating capabilities among the network’s nodes. This can be used in the sensing system for the fusion of multi-aspect angle views of targets. The use of very wideband signals makes the system far more robust in the harsh multipath environments found in MOUT. The concept is illustrated in Figure 1.
1.2 RF-Sensors to Support Urban Warfare

The advanced sensing technology derived from using cooperative and synchronized radios in ad-hoc networks leads itself to the natural application of through the wall sensing. A multi-suite sensor technology including stepped-frequency, Ultra Wide Band (UWB) or synthetic wideband radar technologies for through the wall sensing have been widely recognized and successfully demonstrated to date.

1.2.1 Wideband Tomography

The combination of simultaneous multiple-looks in a network of synchronized sensors offers additional gain against clutter and increases resolution. The derived spatial diversity provides a more robust target recognition capability. Wideband tomography is somewhat different than synthetic aperture systems since it eliminates the need for the “full” synthesis of the aperture. Very wideband waveforms enable the use of incoherent or semi-coherent tomographic imaging methods [1] that exploit the sensing of a target from multiple view angles. Hidden Markov Models [2] for target classification is further enhanced when multiple target-sensor orientations are available [3].

1.2.2 Passive Millimeter Wave Technology for the Detection of Concealed Weapons

Alternative methods for concealed target detection are also being developed. Lockheed Martin Missiles & Fire Control–Orlando (LM M&FC–O) began research into the detection of concealed weapons under the sponsorship of both government and commercial interests in the mid-90s. Initial proof-of-concept tests were developed using non-radiating millimeter-wave (MMW) sensors at W-Band and showed the capability of a rudimentary passive millimeter-wave system to detect both metallic and non-metallic objects concealed under clothing for static subjects (Figure 2) [4].

Based on this initial success, the National Institute of Justice (NIJ) provided additional funding through AFRL to build a brassboard system. This system was used to demonstrate the real-time detection of metallic and non-metallic concealed weapons on stationary and moving subjects at standoff ranges and behind materials such as drywall up to 40 feet away. While producing useful images, initial image quality highlighted the need for better real-time scanning techniques and improved millimeter-wave low noise amplifiers (LNAs). Such upgrades [5] are required to provide the resolution and sensitivity needed for accurate detection and classification of weapons at varying ranges for both indoor and outdoor urban warfare scenarios. The use of the system as an “anomaly” detector to aid in the detection of concealed explosive packages is also being investigated.

The NIJ brassboard incorporated dual linear receiver arrays (2 X 17) consisting of discrete horn antennas which collected and transmitted signals through waveguides to individual radiometer modules. A Cassegrain system was used to form an image of the scene for scanning by the receiver array. The primary mirror aperture was 12 inches, which offers promise for a compact, handheld unit. A PIN diode switch was incorporated at the front of each module to adjust for receiver gain variation by selecting between the scene and a reference load. Behind the PIN switch, a cascade of LNAs, a filter, and a square-law detector diode supplied signal to a video amplifier. Along with the contributing losses from the switch and the input transition from the waveguide, the LNA noise figure was the primary determinant of the overall noise figure and the resultant sensitivity of the system. The NIJ brassboard [6] is shown in Figure 3.

1.3 Organic Platforms Applications

Other wideband sensing and communication packages are being developed for use in organic platforms. The unique
capabilities of wideband signaling combined with biomimetic sensor design has led to the development of high performance, low cost, small-size and low power systems well suited for organic platforms. Micro-Unmanned Aerial Vehicles (UAV) and Small Unmanned Ground Vehicles are among the candidate platforms for bio-inspired sensors. Recent efforts in the system design of an obstacle avoidance sensor for a small UAV resulted in a bio-inspired anti-symmetric UWB/Video fusion system based on the Barn Owl audio/visual target queuing bio-system (Figure 4).

4. SUPPORTING FUTURE NETWORK CAPABILITIES

4.1 Wideband Communications Through Enhanced Waveforms and MIMO Systems

A coherent wideband version of Multiple Input Multiple Output (MIMO) communications is currently under development. In the harsh environment of urban terrain, multipaths create complications and this emerging technology exploits this complexity based on sophisticated signal processing across synchronized nodes to reach data rates close to Shannon’s limit [7]. This wideband MIMO technology is currently being developed to permit robust high data rate transmission in urban environment even for deep fading channels. This technique provides superior Low Probability of Intercept & Detection (LP/LPD) and Anti-Jamming characteristics for the waveforms based on the Coherent Multi-Band waveforms developed by LM ATL.

4.2 Resource Management Supporting Systems

The coordination of radios and sensors in MOUT is crucial to operational success. Another effort is being undertaken for optimizing the utilization of the RF resources, including frequency bands, time of operation and spatial reuse. This resource management for RF operation in MOUT is based on emerging agent technology. This solution creates limited overhead (few percent of total data flow) for the distribution and coordination of the operations of the sensor/radio networks within a squad, platoon, or the company level.

4.3 Mobile Agent Routing

Advanced routing protocols are needed to send information among the networked nodes for MOUT applications. Our ad-hoc networking techniques allow the fast deployment of sensor networks before or at the moment of group deployment. Scaleable ad-hoc quality oriented connectivity and integrated sensor network, with in-network processing capabilities, have been achieved while keeping overhead and processing requirements to a minimum.

Lockheed Martin’s partner Intelligent Automation, Incorporated has developed an ad-hoc mobile network system based on the use of software agents. This Mobile Agent Routing (MAR) protocol is designed to establish and keep connections for an ad-hoc mobile network, given requirements for QoS and priority of connections. The MAR protocol is a hybrid protocol that is both proactive and reactive.

The two main aspects that distinguish MAR from other mobile ad-hoc network (MANET) protocols are that although MAR keeps a connectivity table, it assumes this information is at least partially stale. This assumption forces MAR to introduce elements of reactivity (reactive protocols find routes upon request) in its routing mechanism. The second key distinction between MAR and other MANET protocols is that MAR produces routes that are linked to a specific connection, instead of a specific source/destination pair. The emergent behavior of this cost function is to naturally distribute the routes across available links. In the MAR protocol each node of the network is a potential routing agent. Each of these agents holds data structures in which they store their own view of the network, and their current resource allocation commitments. Using these data structures the network agents can process the data packets and commands issued to them.

4.4 Increased Performance Leads to Increased Requirements

One of the most precious commodities exploited by these future systems is bandwidth. In these systems large bandwidth radios front ends, antennas, Analog to Digital Converter (ADC) and processing capabilities are required because next generation systems for urban warfare need to operate over wide bandwidths (probably greater than a couple of GHz).

A simple example illustrating this case is a set of 8 netted sensor/radios used to create a tomographic image of only 5m² area with a 5 GHz bandwidth from 64 target/sensors positions at 16 bits precision. In this case roughly 482 Kbits of data must be transmitted over a common channel for the fusion at a central node for a single update. This 5 GHz bandwidth results in a 3cmX3cm imaging resolution. To achieve performance across a XNET type system a 10 Mbps data throughput must be sustained across an ad-hoc network in a harsh urban environment for a 20 updates per seconds. This implies that each sensor needs to support at least a 1.25 Mbps communication rate.

5. FUTURE ELECTRONIC AND MMIC REQUIREMENTS

The large bandwidth requirements present unique challenges for the digitizing circuitry and associated RF signal chain.
Clearly performance will bottleneck at the weakest part of the signal chain, therefore next generation electronics must address the need for increased bandwidth for wideband directive antennas, LNA, Variable Gain Amplifiers, ADC with good resolution and low sampling noise, Track/hold devices, filters, etc.

The MAR solution discussed in Section 4.3 is built on an agent infrastructure called Cybele™. The Cybele™ code itself has small memory requirement and has been ported to a hand held Personal Digital Assistant (PDA). It is fully feasible to implement a Cybele™ node in a custom next generation micro-electronics IC chip.

In the case of the concealed weapon passive millimeter radiometer (see Section 3) specific hardware improvement are planned. The LNA MMICs used in the radiometers for this configuration were fabricated on 4-mil thick Gallium Arsenide (GaAs) wafers using a mature 0.1 um gate length PHEMT process. The noise figure for the LNA was 4 to 5 db over a 12 GHz bandwidth centered at 94 GHz with a minimum gain of 15 dB. For a next generation design, LM M&FC-O anticipates the substitution of Indium Phosphide (InP) LNAs, as well as incorporating the antennas directly into the modules to eliminate transition losses. The InP process should reduce the noise figure to 3 dB, provide higher gain per stage, and substantially reduce power consumption since InP draws 30% less current. Along with improved bandwidth, this approach is expected to reduce the noise equivalent differential temperature (NEDT) to less than one degree K, sufficient for indoor concealed weapon detection applications [8].

A key to success in evolving new capabilities has been continued emphasis in advancing both MMIC and transceiver module technology in collaboration with industry partners. Looking into the future, we anticipate greater levels of integration at the chip and module levels to reduce parts count and improve yields. In the ideal case, this will lead to multi-channel modules incorporating integrated single channel chips.

6. CONCLUSIONS

This paper has presented some of the recent developments in emerging sensor and communication systems technology for MOUT undertaken by Lockheed Martin and its partners. The paper briefly discussed the current limitations in hardware and micro-electronics and also offered an overview of the future requirements needed to realize these novel system concepts.

7. ACKNOWLEDGEMENTS

Our thanks to Mr. Caposell of Naval Air Systems Command for the invitation to participate in this GOMACTECH Urban Warfare Special Session and to Mrs. K. Griggs for facilitating our paper submission. IAI’s work on software agent-based ad hoc mobile network protocols and its development of a software agent-based ad hoc mobile network simulator were partially supported by U.S. Army CECOM.

8. REFERENCES


9. BIBLIOGRAPHIES

James Saultz has been involved in LM ATL’s signal processing for many years and currently is leading the business development. Gregory Barnett holds an MS in EE and his research interest are radar sensing, communications and signal processing (member IEEE). Dr. Marc Olivieri holds a PhD in OE with a minor in EE. His research focuses on wideband systems for sensing and communications (member IEEE).

Thomas Radovich is currently a Director at LM M&FC-O. Mr. Radovich is responsible for developing dual-use technologies and implementing technology spin-offs and licenses. Mr. Radovich has been recognized for technical papers and contributions to such professional organizations as SAMPE and AIAA. Albert Pergande has an MS in EE and has been involved in RF and Radar design for 23 years. Mr. Pergande has designed and field-tested many types of radar. He holds several patents in the field of Radar system design, waveform methodologies, and components. Lee Mirth has an BS in EE with over 40 years experience in the defense and aerospace industry with a focus on advanced microwave and millimeter wave components and systems. Mr. Mirth is currently the Program Manager for the millimeter wave concealed weapons detection system that uses passive imaging in a standoff configuration to detect objects under clothing.

Dr. Leonard Hayes is founder and president of Intelligent Automation, Incorporated. Dr. Hayes is founding chairman of both the IEEE Robotics and Automation Society’s Standards Committee, and the Robotic Industries Associated Standards Committee R15.04, and is active in other ongoing standards activities.