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THESIS

IMPLEMENTATION OF NETWORKING-BY-TOUCH TO SMALL UNIT NETWORK-ENABLED OPERATIONS

by

Konstantinos Vasilopoulos

September 2010

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13. ABSTRACT (maximum 200 words)

Command and Control (C2) techniques and procedures radically changed with the emergence of Network-Centric capabilities. The extensive amount of information distributed to soldiers in the modern battlefield often results in cognitive overload. Utilizing the human sense of touch to convey information may avoid information bottlenecks. Tactile interfaces seem to be an alternate way to manage information efficiently, especially in small network-enabled units, thereby enhancing their performance on the battlefield. This transmission of data via physical or electronic touch can provide a robust, rapid, intuitive and secure means of reliable communications.

In this research, the concept of Networking-by-Touch (NbT) integrated into Human Area Networks is being explored as a platform for improving information sharing and collaboration, increasing situational awareness and enhancing decision making. Some military applications that address the use of tactile displays for small ground-battle elements (e.g., a Special Operations Squad) are presented. Additionally, Disruption/Delay-Tolerant Networking (DTN) technology is discussed, as it relates to challenging military ad hoc networks with frequent partitions and intermittent connectivity due to mobility, environmental factors or jamming.

Finally, within the CENETIX/Tactical Networking Topology (TNT) testbed environment, potential experimentation is proposed for testing proof of concept and evaluation of network performance.

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IMPLEMENTATION OF NETWORKING-BY-TOUCH TO SMALL UNIT NETWORK-ENABLED OPERATIONS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AO	Area of Operations
AP	Access Point
API	Application Programming Interface
ARL	Army Research Laboratory
ATL	Assistant Team Leader
BAA	Broad Agency Announcement
BAN	Body Area Networks
BFC	Biometric Fusion Center
Bps	Bits per Second
BPSK	Binary Phase Shift Keying
C2	Command and Control
CENETIX	Center for Network Innovation and Experimentation
CKM	Collaboration and Knowledge Management
COA	Course of Action
COMSEC	Communication Security
COP	Common Operational Picture
COS	Chief of Staff
COTS	Commercial-off-the-shelf
DARPA	Defense Advanced Research Projects Agency
DISA	Defense Information Systems Agency
DoD	Department of Defense
DRS	Diver Reconnaissance System
DSA	Dynamic Spectrum Access
DSS	Decision Support System
DSP	Digital Signal Processing
DTN	Delay/Disruption-Tolerant Networks
EMF	Electro Magnetic Field
EO	Electro-Optic
EWALL	Electronic Card Wall
FCC	Federal Communications Commission

Gb	Gigabit
Gbps	Gigabits per second
GHz	Gigahertz
GIG	Global Information Grid
GII	Global Information Infrastructure
GPS	Global Positioning System
GOTS	Government-off-the-shelf
HAN	Human Area Network
HBIC	Human Body Identification Code
HCI	Human Computer Interface / Human Computer Interaction
HMI	Human Machine Interface
HSI	Human Systems Integration
HVT	High Value Target
IBC	Intra-body Communications
IEEE	Institute of Electrical and Electronics Engineering
IFV	Infantry Fighting Vehicle
IMT	Individual Movement Technique
I/O	Input/ Output
IP	Internet Protocol
IPN	Interplanetary Internet
IR	Infrared
IrDA	Infrared Data Association
ISO	International Standards Organization
JPEG	Joint Photographic Experts Group
JTRS	Joint Tactical Radio System
Kbps	Kilobits per second
LAN	Local Area Network
LCD	Liquid Crystal Display
LLNL	Lawrence Livermore National Laboratory
LOS	Line of Sight
LPI/LPD	Low Probability of Intercept and Detect
MAC	Media Access Control

MAN	Metropolitan Area Network
Mb	Megabit
Mbps	Megabits per second
MHz	Megahertz
MIO	Maritime Interdiction Operations
MIMO	Multiple-Input and Multiple-Output
MIT	Massachusetts Institute of Technology
MMI	Man-Machine Interface
MMS	Multimedia Messaging Service
MOP	Measure of Performance
NAMRL	Naval Aerospace Medical Research Laboratory
NBC	Nuclear, Biological, Chemical
NbT	Networking-by-Touch
NCO	Network Centric Operations
NCW	Network Centric Warfare
NLOS	Non Line of Sight
NOC	Network Operations Center
NPS	Naval Postgraduate School
NSW	Naval Special Operations
NTT	Nippon Telephone and Telegraph
NVG	Night Vision Goggle
OFDM	Orthogonal Frequency-Division Multiplexing
OSI	Open Systems Interconnection
PAN	Personal Area Network
PDA	Personal Digital Assistant
PoS	Point-of-Sale
P2P	Peer-to-Peer
QoS	Quality of Service
R2P2	Rapid Response Planning Process
RATS	Raytheon Android Tactical System
RC	Remote Control
RNIC	Radio Network Interface Control

RF	Radio Frequency
RFID	Radio Frequency Identification
RTO	Radio Telephone Operator
SA	Situational Awareness
SATCOM	Satellite Communications
SDV	Seal Delivery Vehicle
SIM	Subscriber Identity Module
SN	Sensor Network
SNR	Signal-to-Noise Ratio
SOA	Service Oriented Architecture
SOCOM	Special Operations Command
SOF	Special Operations Forces
SOP	Standard Operating Procedure
SUO/SAS	Small Unit Operations/Situation Assessment System
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TL	Team Leader
TNT	Tactical Network Topology
TOC	Tactical Operations Center
TSAS	Tactical Situational Awareness System
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UCF	University of Central Florida
UDOP	User defined Operational Picture
UGS	Unattended Ground Sensor
UHF	Ultrahigh Frequency
UMV	Uninhabited Military Vehicles
USV	Unmanned Surface Vehicle
UWB	Ultra-Wideband
VE	Virtual Environment
VHF	Very High Frequency
VOIP	Voice Over Internet Protocol

WAN	Wide Area Network
WiFi	WLAN products based on the IEEE 802.11 standards
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

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I. INTRODUCTION

A. BACKGROUND

Command and Control (C2) techniques and procedures radically changed with the emergence of Network-Centric capabilities. Today's network-controlled battlespace relies heavily upon "self-organizing (self-forming) last mile mesh networking between man and machine at the tactical level, as well as globally distributed collaboration between tactical and operational command centers enabling flattening of the traditional command and control ties" [1]; that statement is evidence of this change. The optimization of these networks results in synchronization of battlefield elements (e.g., sensors, shooters and C2 nodes). Ad hoc networks play a crucial role in information superiority[1] and C2 of forces. A crucial task in combat is to rapidly bridge the information gaps between strategic and tactical echelons and eliminate unknowns in near-real time by conveying only the most critical information to the soldiers. Such technologies thus become "force multipliers." The relatively new technology of Networking-by-Touch (NbT) in collaborative tactical environments could be such a force multiplier.

A soldier engaged in battle already has a demanding role, and it is unrealistic to expect a soldier to make sense of overloaded visual and auditory channels and perform at his or her best level, especially when it comes to decision making. The extensive amount of information distributed to the soldiers in the modern battlefield often results in cognitive overload. Utilizing other human senses such as the human sense of touch to convey need-to-know information may help avoid information bottlenecks and decrease cognitive overload, hence bringing about operational advantages in the battlefield. Tactile notion seems to be an alternate way to manage information efficiently, especially for small network-enabled units. Recognizing the cognitive demands of the soldier in

[1] Information Superiority is defined in FM 3-0 as "The operational advantage derived from the ability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same."

combat, the transmission of data via physical or electronic touch can provide a robust, rapid, intuitive and secure means of reliable communications.

In this research, the concept of NbT integrated into Human Area Networks (HAN) is explored. Along this line, a feasible platform to incorporate HAN technologies is proposed for improving information sharing and collaboration, increasing Situational Awareness (SA) and enhancing decision-making. Delay/Disruption-Tolerant Networking (DTN) technology is explored to overcome the challenges facing military ad-hoc networks that face frequent partitions and intermittent connectivity due to mobility, environmental factors or jamming. This technology allows partitioned nodes or clusters of nodes to communicate with one another and potentially provide access to location-hidden servers. There is also a discussion about the viability of using haptic[2] feedback, via vibro-tactile displayed information to small ground battle elements in order to integrate awareness of soldiers' surroundings (e.g., Special Operations Squad waypoint navigation or information discovery). Relevant to this area is the description of a simplified cognitive communication scheme and communication procedures for the human-computer interaction based on wearable tactile displays. In addition, an overview of existing marketed products that exploit data transmission via highly adaptive human area networks is provided.

Emphasis is given to the applicability of NbT technology to scenarios that support a range of military or civil operations for small units that require mobility and a highly adaptive ad hoc organization. Such scenarios include Search and Rescue, fire fighting, Special Operations Surveillance Reconnaissance (SR), High Value Target (HVT) tracking missions, medical diagnostics, K-9 control, Maritime Interdiction Operations (MIO), pilot-swimmer communication. Finally,

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[2] Haptic technology, or haptics (from the Greek word "haptesthai"), is a tactile feedback technology that takes advantage of a user's sense of touch by applying forces, vibrations, and/or motions to the user.

using the Tactical Network Topology (TNT) testbed and SA environment, potential experimentation for testing proof of concept and evaluation of network performance is proposed.

B. MOTIVATION AND RELATED WORK

A strong motivation for this research is the potential to integrate new robust technologies into collaborative tactical environments in order to enhance SA for small unit Network-Centric operations. The topic is broad in scope and no specific NbT framework exists for HAN-enabled technologies. This effort provides a framework for understanding *why* and *how* for NbT technologies to support soldiers and then tries to implement it. Definition of the basic principles and exploitation of the potentials of the envisioned “touch” network help present a complete picture. Moreover, the relevant case studies and experiment efforts, with partial use of touch networking are used to show the advantages of NbT implementation. Those initial ingredients are adequate to form a conceptual framework from which more comprehensive findings will evolve through experimentation and theorizing.

C. BENEFIT OF STUDY

Command and control in the Network-Centric battlespace demands extensive coordination among cognitive entities (humans and agents). Hence, the efficient management of establishing connections, updating, sharing and applying information with relation to human interactivity facilitates the decision support process. This is exactly the robustness that NbT technology offers to facilitate the accomplishment of the operational objectives.

D. THESIS QUESTIONS/OBJECTIVES

This thesis explores the challenges facing tactical level in efficiently sharing information in ad hoc dynamically formed networks. The research focuses primarily on developing an understanding of Networking-by-Touch technologies and trends, and explores how the military sector can benefit from them. Tactile Situational Awareness System (TSAS) is a beneficial extension to aid soldiers in performing their mission in a hostile environment.

The thesis answers the primary research question: What effect on Situational Awareness (SA) and speed of Command and Control/Mission effectiveness does using physical or electronic touch have on the transmission of data via highly adaptive human networks? Additionally, the following issues are addressed:

1. The feasibility of a common architecture to integrate Human Area Network (HAN)/Intra-Body Communications (IBC) technologies and its implementation challenges.

2. The implementation of a basic cognitive coding scheme and communication procedures for the exchange of information between the human operators and the C2 nodes and/or sensors.

3. The establishment of performance metrics that best support the evaluation of the proposed technology.

E. THESIS OUTLINE

The methodology used in this thesis consists of the following steps: First, it explains the potential of NbT technology and shows the reader why it is relevant and beneficial to collaborative networking environments as a force enabler to Network Centric Operations. It then describes and summarizes relevant literature to improve knowledge of the subject, and demonstrates the practice and prior research that this effort is built upon. The next step is to present analytical examples, case studies and application scenarios of NbT implementation, and to extend those further by proposing optimization techniques that better serve small network-enabled units. Finally, after developing the tactical NbT concept and proposing a framework for its management, this thesis extends the research to the field environment and tests the feasibility and functionality in specific operational domains using the experimental domain of NPS's Center for Network Experimentation and Innovation/Tactical Network Testbed (CENETIX/TNT) architecture and TNT MIO experiments.

The thesis organization includes five chapters. This first chapter is the thesis introduction. Chapter II provides an overview of NbT technology based on conducting a review of existing literature and examining some robust networking and communication techniques like disruption-tolerant networking, HAN/IBC and tactile communications. The focus is on the integration of these systems within an ad hoc network environment in order to enhance Situational Awareness. It also explores the application and integration possibilities for NbT into tactical networks within the Global Information Grid (GIG), by examining potential scenarios and applications regarding tactile notion capability for small units. Some particular applications presented involve intelligent communications pertaining to threat identification or navigation aids.

Chapter III provides the framework for an adaptive network with DTN capability, in discrete time and space for small units, enabled by "touch" inputs/outputs, and its interface with ad hoc mobile networks. Additionally, it describes a model for using social networks as a transmission medium and its design considerations and limitations.

Chapter IV suggests the extension of this research effort to the field environment. It assesses the adaptation of the proposed technology and the implementation challenges in TNT MIO-oriented field experiments and examines its feasibility and functionality in specific operational domains.

Lastly, Chapter V presents a summary of the work along with the conclusions and suggestions for further research.

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II. NETWORKING-BY-TOUCH TECHNOLOGY BACKGROUND

A. SITUATIONAL AWARENESS (SA)

In this section, the thesis introduces the significance of Situational Awareness (SA) for the warfighter and underlines the importance of the decision-making process in the modern network-enabled battlespace. In addition, there is an introduction to the human aspects of networking often overlooked with the ubiquity of complex networked communications, and provide soldiers rapid availability and dissemination of information, hence resulting in more competitive advantages on the battlefield, especially for small network-enabled units.

1. The Warfighting Advantage

The current revolution in military affairs has its roots in the explosive advance of information technology. Vast amounts of data are assimilated, processed and made available to military users. Modern military commanders are closely coupled with their battlefield forces through Command and Control (C2) systems. A C2 system is composed of a number of subsystems that come together as nodes of a network of (a) sensors, (b) navigation components, (c) command and fusion centers, (d) communication links, and (e) decision components [2]. Command decisions rely on information and intelligence that flow through these systems. In other words, they are based upon the understanding of tactical and operational situations. Situational Awareness (SA) is simply knowing what is going on around you. It is the perception of the elements in an environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future [3]. For a given operator, SA is defined in terms of the goals and decision tasks for that job. The operator today is challenged by the “information gap” (Figure 1), which is a dazzling array of data, often changing very rapidly, that needs to be perceived and comprehended [4]. This Figure shows on the left side this dazzling array of data perceived in a complex environment and needs to be integrated, sorted and processed to obtain the final product in the right side.

No doubt, SA is a critical aspect of human decision-making. The ability to develop a higher level of situational awareness, in less time than an adversary, combined with an ability to act on it, is a source of significant warfighting advantage [5].

Figure 1. The information Gap (After [4])

2. Network-Centric Battlespace

Situational Awareness demands an extensive use of the Global Information Infrastructure (GII), which is a worldwide interconnection of communication networks, computers, databases and electronic equipment that collect, process, transmit and disseminate information. Network Centric Warfare (NCW) has been defined by the DoD’s Force Transformation Director as

> an information superiority-enabled concept of operations that utilizes the GII to generate increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, and higher tempo of operations, greater lethality, increased survivability, and degree of self-synchronization.[5]

Evolving from platform-centric warfare, network-centric warfare integrates a distributed system of C2 sensors and weapons called a grid, which is composed of three sub grids: the global information grid (GIG), the sensor grid and the shooter grid [6]. Figure 2 shows the transition from the scattered platforms, services or locations of C2 of forces (on the top), to a unified Network-Centric platform that provides significant information advantage (in the middle section), whereas fewer forces are applied but with superior performance (in the bottom section).

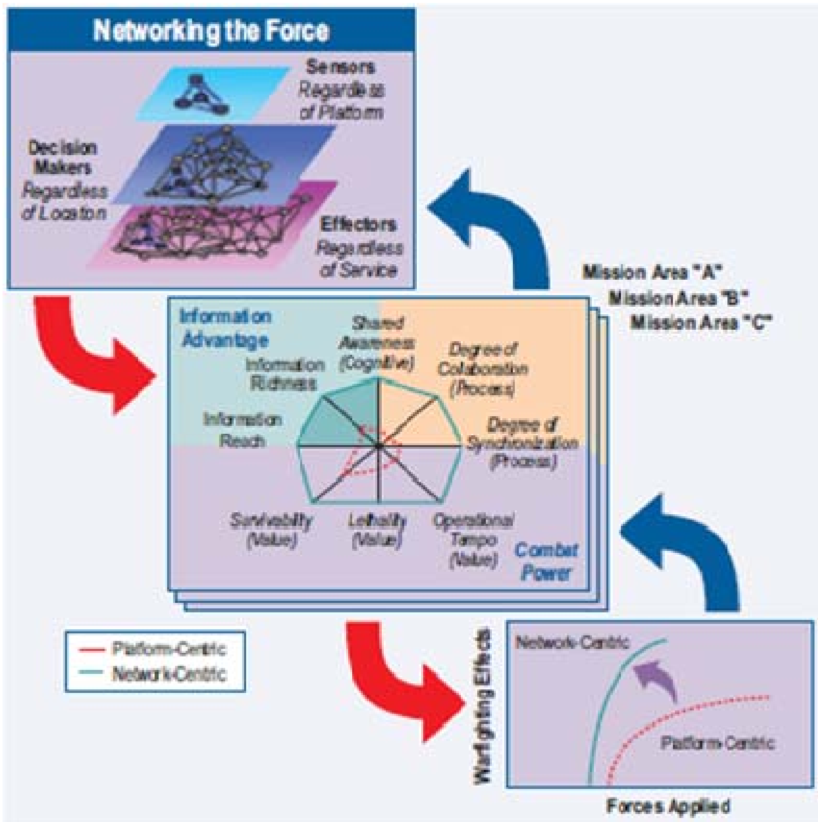

Figure 2. The new rules of information age warfare and NCW (From [5])

The GIG is a deployed tactical sensor and weapons network that provides the infrastructure for plug-and-play of sensors and shooters [6]. It exists in space, and at all altitudes, on land, and under sea. A physical, permanent and fault-tolerant network receives, processes, transports, stores and protects the information while it makes communications and sensor data available to the warfighter. The sensor grid is composed of air-, sea-, ground-, space-, and cyberspace-based sensor nodes [6]. It is transient and exists only for a task. It is re-formed for every mission to perform dynamic sensor tasking and data fusion [6]. The shooter grid consists of weapons and jammers. It is also a transient grid where the parts are physical. It exists for the task only and is re-formed for every mission.

From the previous description, it is a fact that networked communications are becoming ubiquitous on the battlefield; soldiers are evermore reliant on the rapid availability of information throughout every echelon of command. Tactical commands mainly depend on mobile ad-hoc networks (MANETs) that have different physical and performance characteristics than local area networks (LAN) used by higher commands. The military's motivation for ad hoc networks at the tactical level arises from an imagined operation where each soldier carries a wireless network station and those stations form a communication system automatically. Those networks are self-organizing (self-forming)--i.e., each wireless station seeks to connect with neighboring stations. Those connected stations choose a topology and establish routing that allows any station to reach any other station. Today's networked battlespace relies heavily upon this self-organizing, last mile mesh networking between man and machine [1]. Within this complex collaborative environment, man and machine interaction is continuous.

3. Common Operational Picture (COP)

Situational Awareness is also defined by the U.S. Army's Training and Doctrine Command in the 525-5/Aug 94 Force XXI Operations pamphlet as "the ability to have accurate real-time information of friendly, enemy, neutral, and noncombatant locations; a common, relevant picture of the battlefield scaled to specific levels of interest and special needs." Towards this definition, a combination of digitization and information exchange over broader band networks is employed to develop a Common Operational Picture coupled with a shared whiteboard for collaboration over the map of the battlespace. This platform reduces some of the ambiguity and confusion of combat to identify clearly the positions of friendly forces and the known positions of the enemy (see Figure 3).

Figure 3. Main application Software and rugged Hardware for the Force XXI FBCB2–BFT system[3] (From [7])

The development of a common operational picture across a broad spectrum of mission areas significantly increases the warfighter's awareness and understanding of tactical and operational situations. In practice, continuous snapshots gathered from the battlefield and transferred to the commander build situational awareness. Through SA tools for mission planning, mission execution and after action review, soldiers can achieve globally distributed collaboration

[3] The Force XXI Battle Command Brigade and Below—Blue Force Tracking (FBCB2–BFT) system has revolutionized tactical command and control and situational awareness. The system links communication devices, sensors, vehicles, rotary-wing aircraft, and weapons platforms in a seamless digital network—the Tactical Internet (TI)—to provide a clear, continuous, and common picture of the battlefield (From [7]).

between tactical and operational command centers, and various interagency experts. At the tactical level, adaptive ad hoc wireless mesh networking between man and machine, with the use of collaborative technologies, plays a crucial role in information exchange and C2 of forces. Better information exchange ability results in a quick refreshing of the SA view in each tactical computer; consequently, SA is significantly effected by the information processing capability of those tactical computer displays. For example, in simulated combat scenarios, warfighter access to remote data bases (i.e., a Blue Force Readiness and Red Force Tracker databases), contributes to mission planning speed and quality, and hence, to increased NCW combat effectiveness.[4] One of the most advanced versions of these simulation technologies is Defense Information Systems Agency's (DISA) User Defined Operational Picture (UDOP), with an e-collaboration whiteboard with shared map planning and voice functionality [8] (Figure 4).

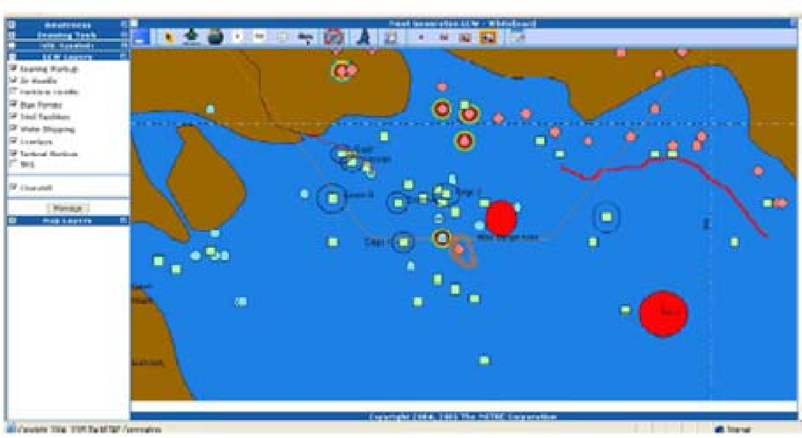

Figure 4. DISA's User Defined Operational Picture (UDOP) Screenshot of Operation Storm Petrel (a Persian Gulf air/sea counter-terrorist combat scenario) (From [8])

[4] In the approach adopted here[8], variably equipped warfighting teams are experimentally created in a controlled Human-In-The-Loop (HITL) experiment utilizing the JTLS war game simulator, and their performances are systematically related to combat outcome. The tool provides for a distributed command team of joint warfighters collaborating and replanning over an IP Network with access to remote operational planning databases, while engaged in simulated combat scenarios, compared to the effectiveness of war fighter performance, employing current baseline condition technology.

B. TACTILE COMMUNICATIONS

1. Introduction

Tactile communication refers to what is communicated through the sense of touch. Touch may be the most primal or basic form of communication in nature: it is the way things are communicated to infants, way before infants learn anything about other modes of communication [9]. The sense of touch helps to maintain or reinforce situational awareness of the surrounding environment (e.g., a touch triggers an instinctual response). Tactile messages tend to convey aspects of emotional and attitudinal states like anger, love, warmth, coldness, hostility, etc. Its major advantage is that humans can often receive tactile communications even when they have mental overload or are extremely stressed. It is necessary, however, to describe the ongoing esoteric procedures that allow human interaction with the surrounding environment.

2. Cognition

Cognition provides the internal structures and processes that are involved in the acquisition and use of knowledge, including sensation, perception, attention, learning, memory, language, thinking, and reasoning [10]. Cognition throughout life is a broad interaction between knowledge-driven processes and sensory processes, and between controlled processes and automatic processes [11]. Over time, there is a trade-off between the amounts of surface information retained in the internal representation of objects or events (i.e., bottom-up processing) and the amount of meaning that is incorporated (i.e., top-down processing). When there is exposure to a stimulus, a sensory representation (e.g., an image, an icon, or an echo) is constructed that encodes nearly all the surface characteristics of the stimulus (e.g., color, shape, location, pitch, and loudness). Of course, the information is short-lived [11]. Research evidence [12] suggests that extraction of information from those types of representations take place in two stages, a feature-analysis stage and an object-recognition stage. During the latter stage, that attention (i.e., controlled processing) and previous knowledge come into play.

This previous description helps provide better understanding of the data-extracting procedure that occurs out of the continuous information flow that humans use to evaluate a complex environment. The operational environment of today's Armed Forces is increasingly cognitively demanding, information centric, and sensor-oriented. The battlefield is not a single geographic location, rather it is distributed over a wide electronic web of sensors, cognitive agents, and effectors (i.e., the warfighters, the weapons systems and other sensors). Figure 5 depicts three viewpoints on elements in the battlespace: the Physical, the Informational and the Cognitive. The Physical layer is extended into a much broader Informational domain and ultimately entailed to an overall Cognitive environment where the shared Situational Awareness is acquired and maintained.

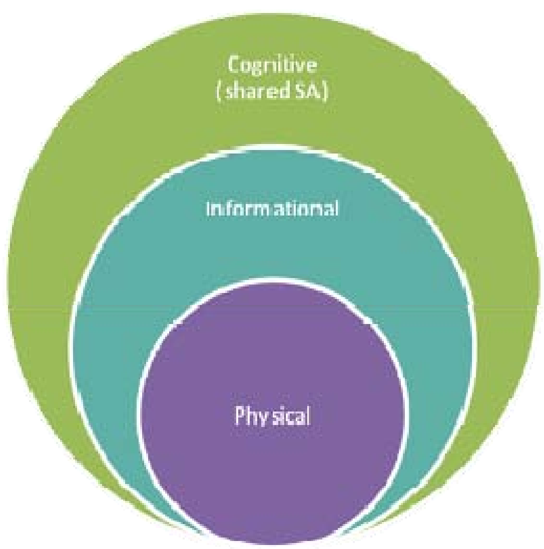

Figure 5. Viewpoints on Elements in the Battlespace (After[8])

The Joint Operations Concepts (JOCs) document, reflects the vision of a transformational, network-centric joint force, as expressed in terms of the three key domains of warfare: Physical, Information, and Cognitive—see Figure 6.

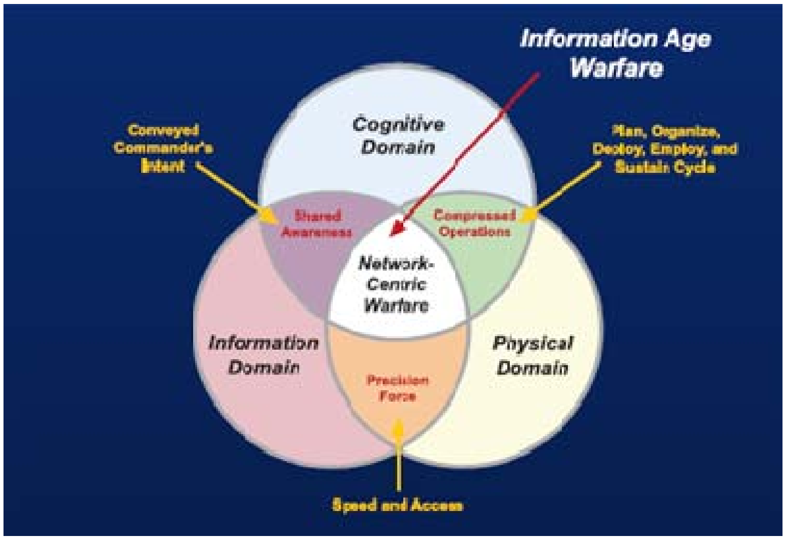

Figure 6. The three key domains of warfare: Physical, Information, and Cognitive (From [5])

In general, the net-centric processing cycle entails sensors pushing information to cognitive agents who filter, fuse and send it to other agents, and ultimately processed information is forwarded for action at the effectors' level. This network is a cognitive system with inputs from the environment; it does processing and outputs results back to the environment through. For the cognitive agent in this system, information overload is the rule.

Figure 7 shows a sectional view of a network divided into the physical, communication networks, information, and social/cognitive layers [12]. Each layer contains descriptions of supporting technology or human behavior existing in that layer. The arrow connecting the layers suggests that each layer cannot exist in isolation—i.e., each depends upon other layers for inputs or actions. For example, a sensor existing in the physical layer detects an object in the environment and sends an image that is routed through the communication network to an operating system supported by the information layer[5]; this image is viewed by an operator who acts upon it in the social/cognitive domain [12].

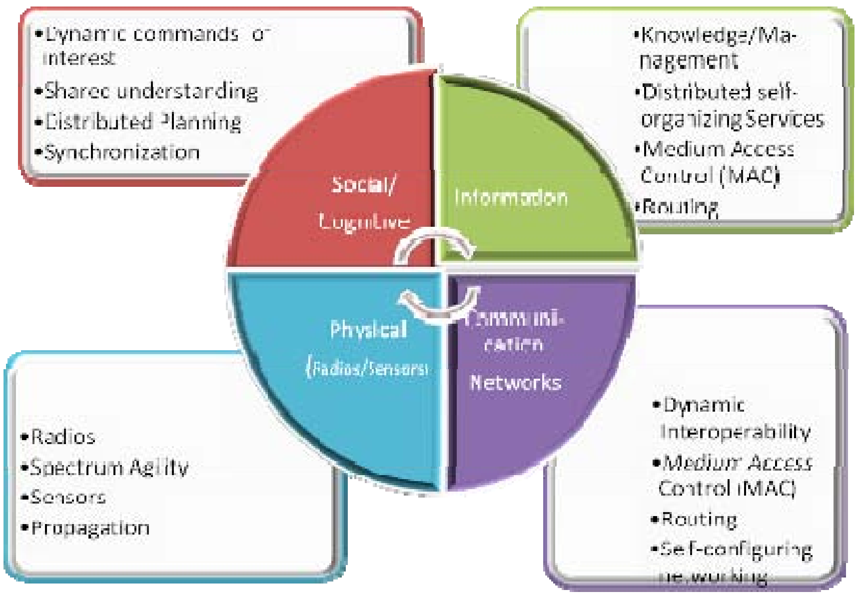

Figure 7. Physical, Communication Networks, Information, and Social/Cognitive Levels of a Network (After [12])

3. Haptics (Physiology of Haptic Perception)

The field of tactile response is formally known as Haptics, from the Greek word "haptesthai," meaning "to touch." Haptics is one of the first senses that humans encounter during development [13]. The sense of touch is often overlooked as a method of communication, particularly when considering man-machine interfaces such as conveying information from aircraft and automotive instrumentation. Significant research exists in the area of tactile sensory perception, and in recent years, government-funded programs have advanced the state of the art in technology and enhanced the understanding of human tactile response. To address this mechanism, a brief background on the interaction of the human body and haptics is necessary.

[5] This term comes from the Open Systems Interconnection (OSI) Model that defines the communications process into 7 layers, and divides the tasks involved with moving information between networked computers into seven smaller, more manageable task groups.

The sensibility of individuals interacting with the world adjacent to the body, or how the body "feels" and interprets physical sensations, occurs through the response of nerve and pressure sensors on and beneath the body's largest organ, the skin [13]. The skin functions as one large haptic system. The skin is receptive to stimuli including changes in temperature, pain, and pressure. Tactile perception can be induced by directly stimulating the human skin, which is sensitive to pressure (positive or negative), vibration, temperature, electric voltage and current. The skin (and muscles) contains a variety of sensory organs called receptors, sensitive to pressure or vibration. Those include pain receptors, heat flow receptors (for sensing temperature) and mechanoreceptive[6] units. These functional groups are composed of specialized sensory organs that include the Meissner corpuscles, Merkel's disks, Pacinian corpuscles (see Figure 8), and Ruffini Endings [14].

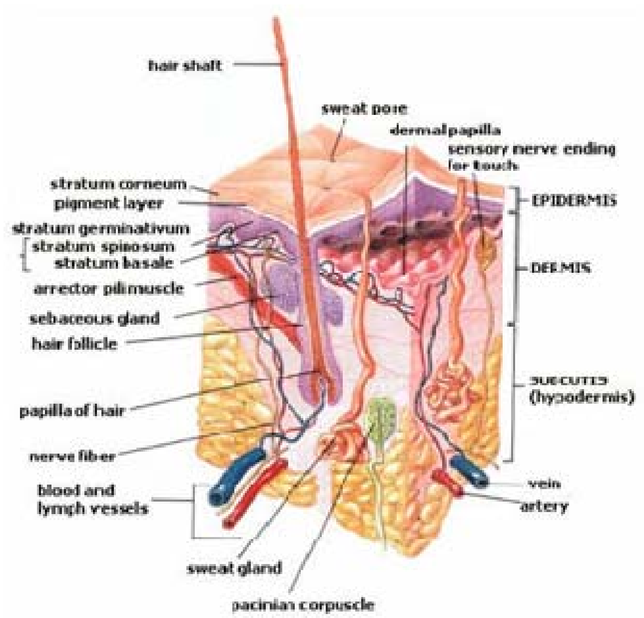

Figure 8. The Pacinian corpuscle (labeled at bottom) inside the human skin (From [14])

[6] The mechanoreceptors are embedded in the upper layers and when activated, they transmit signals to the brain, through nerves.

The Pacinian corpuscles, the largest of the skin receptors and located deep in the skin and cover 13 percent, are the most sensitive and respond to input from high frequency vibration stimuli from 50Hz to 600Hz with optimal sensitivity around 400Hz [15]. These corpuscles serve as acceleration detectors and vibration sensors and allow a high sensitivity to acceleration and vibration from sensor devices placed next to the skin. The effect of stimuli decays rapidly after onset. Pacinian corpuscles discharge only once per stimulus application, hence, are not sensitive to constant pressure [15].

Researchers like Engineering Acoustics Incorporated (EAI) developed Tactors to exploit the sensitivity of the skin for communication of information. Tactors are small transducers designed to optimize skin response to vibration. The devices implemented so far exploit the modalities of the skin's sensors and especially the characteristics of Pacinian corpuscles. The Tactors are used to provide communication to replace or supplement audio and visual input, especially under circumstances where audio and visual cues can be missed. Tactor designs can be classified into the following major categories based on the modality used: pressure, vibration (mechanical energy), electric field and temperature (or thermal flow) [16]. Furthermore, the mechanical or electrical stimulation of the receptors are classified the devices into three categories: the first class includes pressure (exerted by pin devices) [17], vibration [15], [18], surface acoustic wave [19], electrorheological[7] [20], and magnetorheological[8] fluid-based devices [21], that stimulate the mechanoreceptors using mechanical energy and exploit the modality of each mechanoreceptor [19]. A second class of devices directly activates nerves using an electric field [22]. A third class uses focused ultrasound in order to activate receptors directly or through ultrasound radiation pressure [23]. The previous modalities are mainly used to present

7 Electrorheological (ER) fluids are suspensions of extremely fine non-conducting particles (up to 50 micrometers in diameter) in an electrically insulating fluid (from Wikipedia).

8 A magnetorheological fluid (MR fluid) is a type of smart fluid in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid greatly increases its apparent viscosity to the point of becoming a viscoelastic solid (from Wikipedia).

spatial information, whereas thermal flow is used to add quality characteristics in the data presented, for example simulating color in vision. Some applications combine different modalities by selectively activating different receptors and creating a richer communication. Movement and energy comes from solenoids, voice coils, piezoelectric crystals, Remote Control (RC) servo-motors, Shape Memory Alloys, pneumatic systems, RF antennas, electric field and magnetic field [16].

Based on the previously described technologies, there is a growing family of applications for tactile displays, both hardware and software. Software applications are designed predominantly for the Windows environment; however, the lack of standardized hardware has resulted in software that strongly depends on the implementation used, is embedded in the hardware, or assists the hardware. Currently, there is no universal application that communicates with the hardware through a driver.

Some indicative recent application areas in haptics include: military situational awareness systems, text and graphics applications, medical applications, entertainment and educational applications, engineering applications-assisting the blind and visually impaired, K-9 control, virtual environment (VE) applications, tactile displays embedded in consumer electronics and wearable devices etc., which are further exploit later in the chapter.

4. Touch

The body's sense of touch is a potentially versatile channel for the conveyance of directional, spatial, command, and timing information. Touch is a new avenue of communications. This way of communication takes advantage of a simple fact about human sensory perception—tactile pathways are "always on" [24].

The following scenario [24] helps describe how a haptic communication system could work: consider an NFL game being played in a domed stadium where the noise interferes with audio transmissions. The NFL allows one-way communication from the coach to the quarterback through a radio receiver in the quarterback's helmet. As an alternate means of communications, the quarterback could be wearing a belt or a vest with a half dozen tiny electronic devices attached to it (see Figure 9). With this newfangled wireless tactile system, when the coach has a message to pass along, he remotely activates one of the tiny devices, within the quarterback's belt or vest near the quarterback's navel, and it vibrates to get the player's attention. Then in quick succession, three more devices on the player's stomach and lower back tap out a message in something akin to Morse code: on the next snap, the coach wants the team to execute a particular pass play. If the NFL would allow it, the quarterback could tap one of the devices in order to answer "Roger," or tap out a coded message on several of the devices saying he prefers another play. In addition, the stimulators also serve as biosensors, able to track the physical well-being of the wearer tracking things such as heartbeat and respiration at any particular moment.

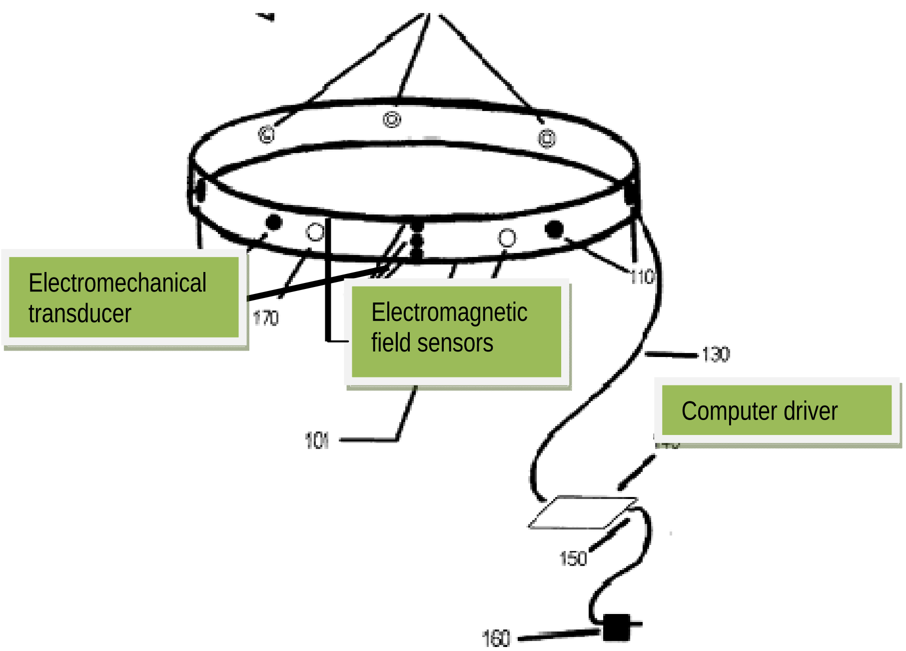

Figure 9. Vibro-tactile waist belt (From [25])

Now, consider another simple scenario: John loves music. While John was walking, he ran into Mary, who was listening to music with her wireless portable music player and wireless headphones. John had his high-quality wireless headphones, so he wanted to listen to the music together by connecting his headphones to her music player. All he had to do was push two buttons. First, he pushed a button on her music player, and then pushed a button on his headphones. This simple operation established a connection between these two devices, and he was able to enjoy the music. Alternatively, he might have shared the music with her merely by touching his cell phone to her music player and automatically download and listen to the music file through his headphones. In the case above, we generally need complicated setup operations such as: First, John tells Mary the name of his headphone, then she searches for this name on the network member list displayed on her music player. If there are many devices in the network, the member list is so large that this search operation is cumbersome, and sometimes other devices may have the same name. In other words, as with every other wireless protocol, devices must proceed through the necessary stages—search, discovery, selection, authentication, connection, and transfer [26]—in order to complete a desired activity. However, with this framework, all previous steps are collapsed into a single motion: the touch. John can request the connection by simply pushing buttons instead of performing complicated setup operations. This framework could enable users to connect various devices by just touching them (or bringing them into close proximity). Ideally, this connection management framework is extendable in an ad hoc network environment where any devices that do not know each other can interact and cooperate without a connectability relation provided beforehand by an application protocol and server [27]. The use of a mobile code is suitable for designing such an extendable framework [28].

Nowadays, a technology-enabled person might carry some of the following devices: a cell phone, a GPS, a digital camera and/or video recorder, a media storage, a Personal Digital Assistant (PDA), a netbook, a remote vehicle access key, etc. Consequently, these devices provide high-level services for users such: GSM voice, texting and video streaming, Media Storage/Access, Internet Access, Voice-over-IP (VoIP) services, file sharing and downloading, application handling, navigation and direction finding, WiFi, WiMax, Bluetooth, E-mail, document editing, and many more. From the previous simple example, we now advance to an integrated environment where the above devices and services of modern technology converge in order to provide adaptive solutions to the user. Touch networking provides the platform for this enhanced functionality of the system. Since many of the devices provide redundant features, those operating at lower networking levels are streamlined, allowing the higher level network components with better processing and storage power to receive up-to-date information. Configurable devices, worn on the person, conform to the user's preferences and provide tailored functionality by learning through the physical interactions within that user's environment [29]. The user's preferences are customized to provide a level of comfort and his profile is continuously updating through the touch network.

C. DELAY/DISRUPTION-TOLERANT NETWORKS (DTN)

1. Concept of DTN

The basic concept of DTN has its origin in the work on Interplanetary Internet, an outer-space network project [30]. A decade ago, researchers implemented the Interplanetary Networking (IPN) basic design to terrestrial networks and established the term Delay/Disruption-Tolerant Networking (DTN). The most attractive feature of DTNs is the ability to address networks that exhibit intermittent connectivity [31].

Various factors are responsible for sparse connections such as power fluctuations, mobility, wireless range and interference, network partitioning, malicious attacks or catastrophes. Thus, the so-called challenged networks, shown schematically in Figure 10, often break the end-to-end network connectivity assumption; therefore, the current TCP/IP model is not always applicable. A DTN acts as an overlay on top of regional networks, including the Internet that provides interoperability and manages long delays. The wireless DTN technologies include radio frequency (RF), ultra-wide band (UWB), free-space optical, and acoustic (sonar or ultrasonic) technologies [30]. The applications of DTN are highly diverse and extend to a wide variety of areas: interplanetary networks for deep space communications, terrestrial networks connecting mobile wireless devices, sensor networks for ecological monitoring, transient networks to benefit developing communities, ad hoc networks to disseminate information in tactical or roadway environments, and disaster recovery networks [30]. This technology is especially useful to the military, which is transforming into an agile, distributed network-centric force, where DTN accommodates the new doctrine for accessing mission information even under disruptions to connectivity in the GIG.

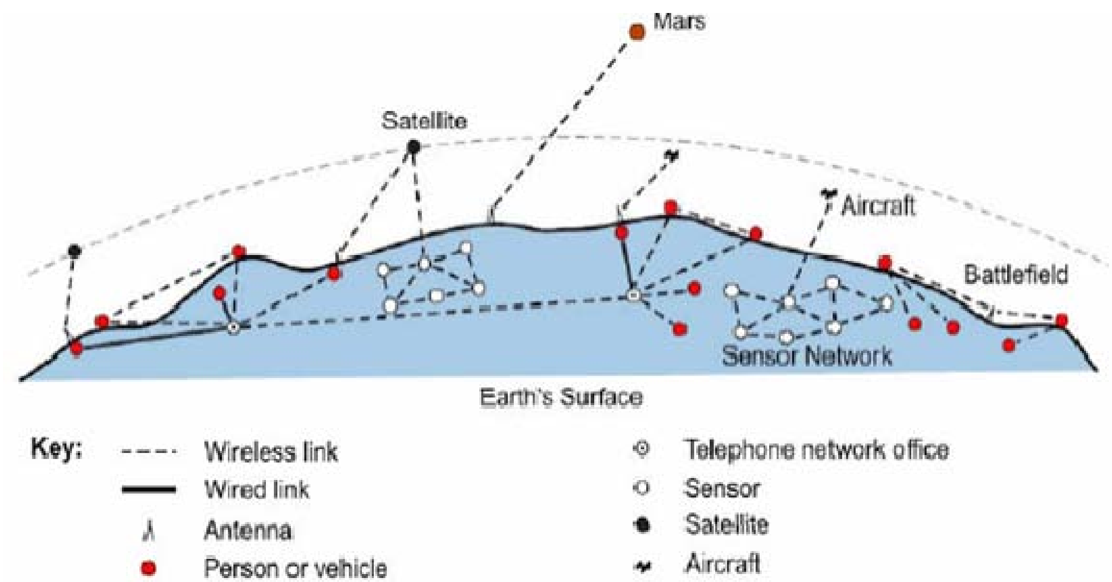

Figure 10. Challenged networks (From [30])

The design of DTN architecture, protocols, interoperability, security, and management is very challenging due to the diversity of network environments and the inherent uncertainty of network conditions.

2. Why a Delay-Tolerant Network?

What is the advantage using DTN technology for collaborative mobile ad hoc military networks? What is the problem we are trying to solve? Mobile communication systems are adopting and depending upon Internet technologies to enable combined voice/data communications. One of the inherent characteristics of any wireless communications system is the occasional loss of connectivity. This loss has a disproportionate effect on transport layer operations, particularly when there are multiple unstable hops in the path. Commercial internet technologies generally rely on a benign communications environment. This environment assumes that an end-to-end path always exists and that power, bandwidth, storage, and network access are readily available. In the DoD's evolving wireless tactical network environment, connectivity often fails, due to weather, mobility, ground morphology, jamming or even destruction of nodes. When the two endpoints are not present on the network simultaneously, even if there are reliable opportunities available through intermediate nodes, it makes it impossible to determine a path, halting the flow of data [32]. As a result, the operation of such tactical networks in heavily stressed battlefield environments does not coincide with the IP-based network assumptions. Nevertheless, the operational aspect of military networks is diverse. Nodes may sleep to save power (e.g., sensor networks), mobile devices may leave each other's radio ranges (e.g., vehicular networks) and a sender and receiver can make contacts at an unscheduled time (e.g., Special Operations/opportunistic networks). Another situation might occasionally utilize covert network nodes that use unconventional networking techniques like Networking-by-Touch. Consequently, in all these scenarios, DTN technology addresses the special network characteristics depicted in Table 1.

Network Disruption Status	Network Characteristics
Intermittent connectivity	• No end-to-end path between source and destination (network partitioning) • In mobile communication nodes links can be obstructed by intervening bodies and when nodes must conserve power or preserve secrecy, links are shut down
Long or variable delays	• contribute to end-to-end path delays • introduce high latency • defeat IP protocols and applications that rely on quick acknowledgments of data
Asymmetric data rates	• Moderate asymmetries of bidirectional data rates are supported by Internet. • If asymmetries are large, conversational protocols are defeated
High error rates	• Bit errors on links require correction (more bits and processing) or retransmission of the entire packet (results in network traffic).

Table 1. Special Network Characteristics for DTN (After [30])

The Defense Advanced Research Projects Agency's (DARPA) Advanced Technology Office (ATO) is soliciting proposals under the Broad Agency Announcement (BAA) 04-13 for the development and demonstration of key technologies based on several "problem areas" in the implementation of DTN [33]. The Disruption Tolerant Networking program will develop and demonstrate technology that provides network services when no end-to-end path exists through the network and additional network behavior and functionality is required as DoD transitions from conventional networks to more dynamic, self-forming, peer-to-peer architectures, such as Mobile Ad Hoc Networks (MANETS).

3. Key DTN Architecture

DTN technology works opportunistically and uses a type of “persistent storage” into the network nodes to overcome connection disruptions. DTN suggests a reliable overlay architecture for asynchronous Store-and-Forward messages, called Bundles with arbitrary size and forwarded hop-by-hop between DTN-nodes (bundle routers) [34]. DARPA's DTN program aims to provide delay tolerance by organizing information flow into these finite lifetime bundles, and route them through "custodians" that increase the capabilities of traditional routers by persistently storing the bundles and then advancing them to the next available node en route to their destinations. With this method, the bundles are routed through an "intelligent" network that can manage their delivery to the maximal extent permitted by the available topology [34].

The key architecture for the DTN, as depicted schematically in Figure 11, is based on message-oriented minimal interactivity, routing across network disruption with on demand, scheduled, predicted and opportunistic connections, store and forward operations, and overlay above the transport layer [33].

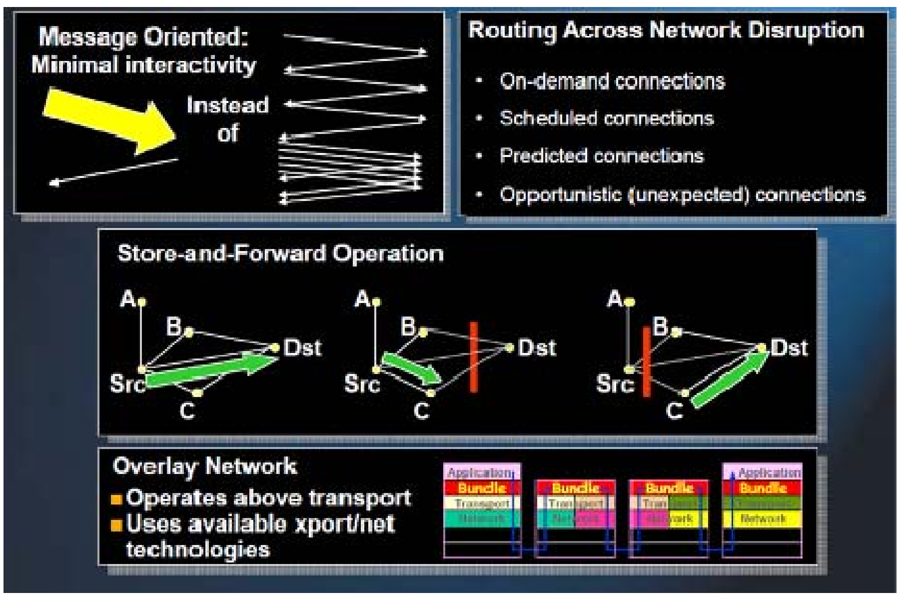

Figure 11. Key DTN Architecture Concepts (From 33])

As shown in Figure 12, DTN gateways interconnect regions running potentially dissimilar protocol stacks by operating above the transport protocols in use on the incident networks.

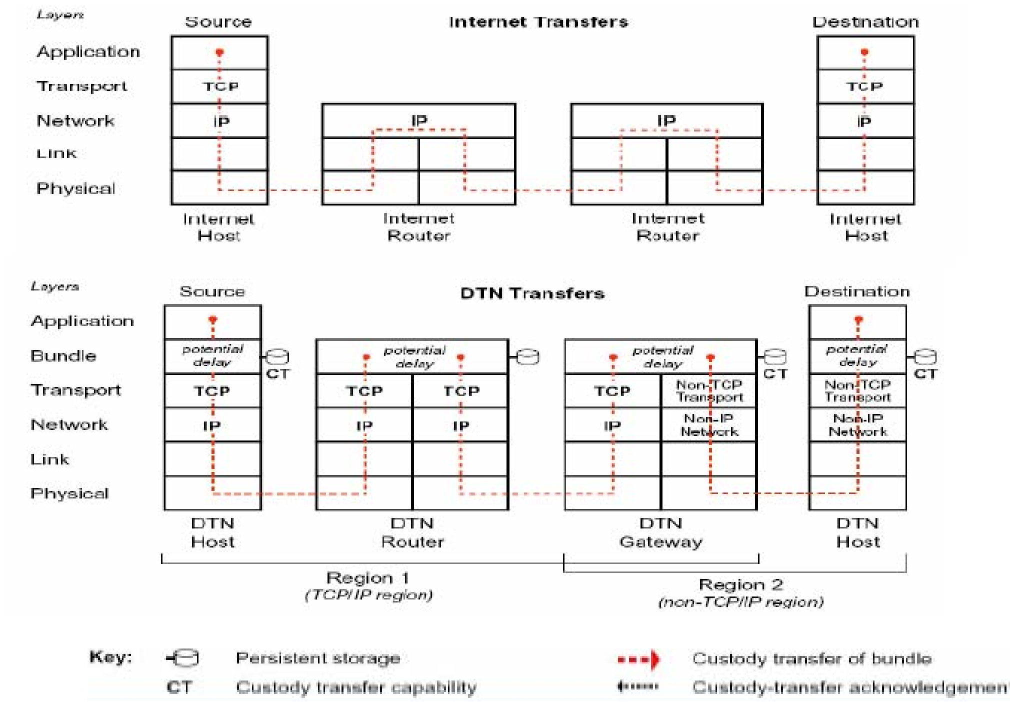

Figure 12. Difference between DTN and Internet (From [30],[35])

Figure 13 illustrates the implementation structure for a bundle gateway including a number of transport-protocol-specific convergence layers used to add reliability, message boundaries, and other features above those transport protocols requiring augmentation.

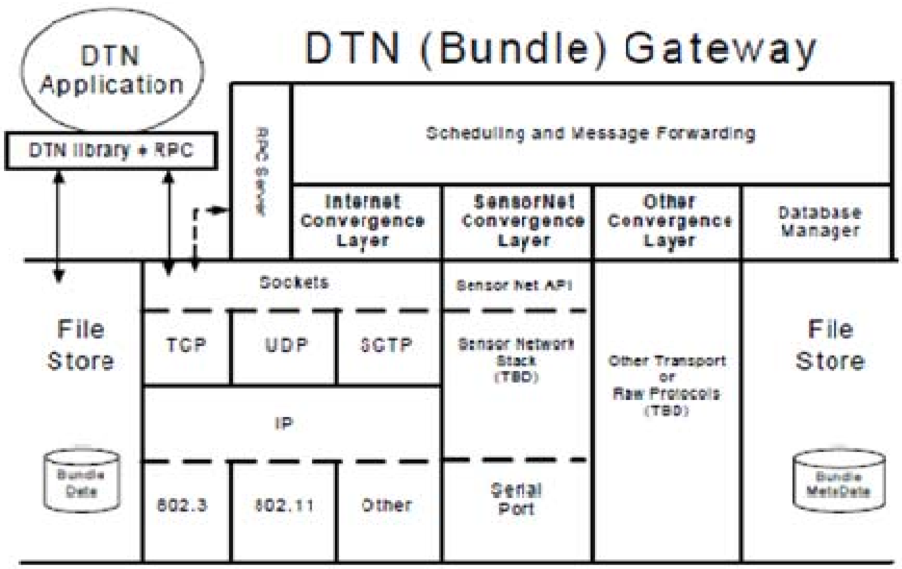

Figure 13. Structure of a DTN gateway. Multiple convergence layers, one per protocol stack, provide a common interface to the message scheduler/forwarder (From [36])

DTN routing takes advantage of mobile nodes (e.g., soldiers in a squad with wearable communication equipment) in an entirely new way, by using them to "haul" data when there is an obstacle in the path either geographic, structural or presented by an enemy threat. Especially for ad hoc touch networks that establish end-to-end connectivity scarcely, or in a discrete time and space, the DTN approach would be very beneficial. In the DARPA DTN program, researched military features with a Delay Tolerant mechanism show 100 percent reliable delivery of data with less than 20 percent availability of links with greater than 80 percent utilization of link capacities [37]. The DTN approach consistently outperformed traditional end-to-end approaches across a wide range of network disruption (Figure 14). Under certain worst-case network dynamics, DTN was able to deliver data reliably, while the traditional end-to-end approach broke down and delivered no data at all [36].

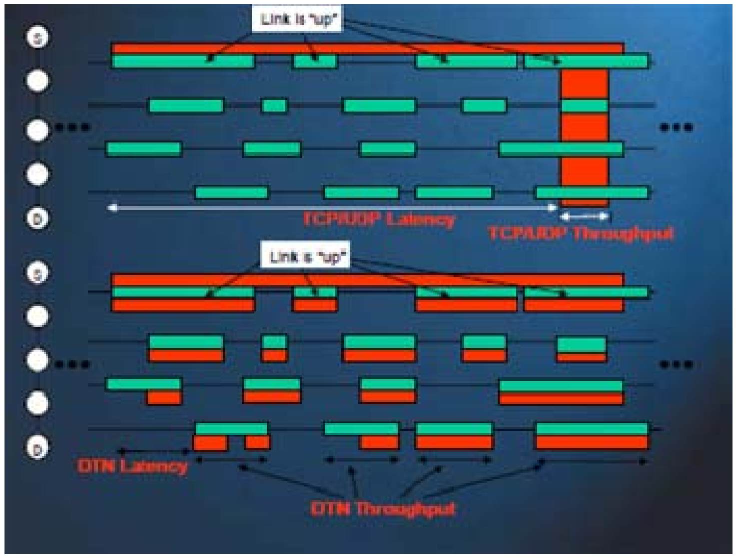

Figure 14. DTN vs End-to-End Internet Operation (From [33])

Figures 15 and 16 illustrate the positive effect of DTN services on unreliable links. Figure 15 illustrates the bandwidth usage of a blue force tracker client operating over an unreliable link. To maintain synchronization of server-client when network interruptions occur requires the additional use of bandwidth to retransmit any lost packets [32].

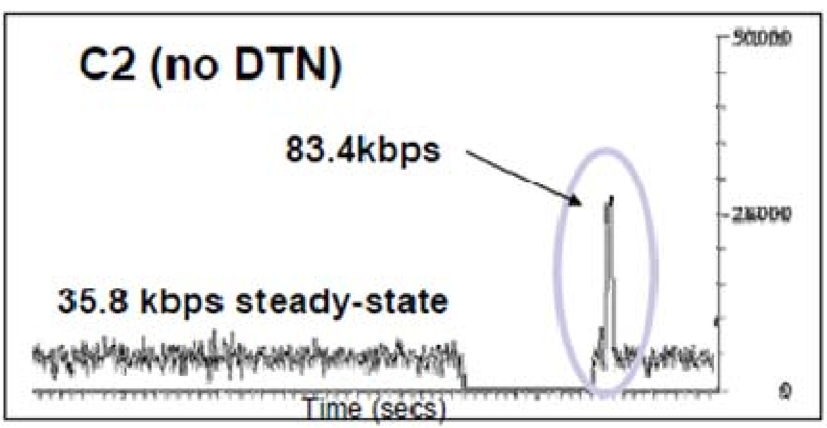

Figure 15. Typical BW consumption without DTN (From [32])

Figure 16 illustrates the same applications using end-to-end DTN services instead of the TCP transport layer.

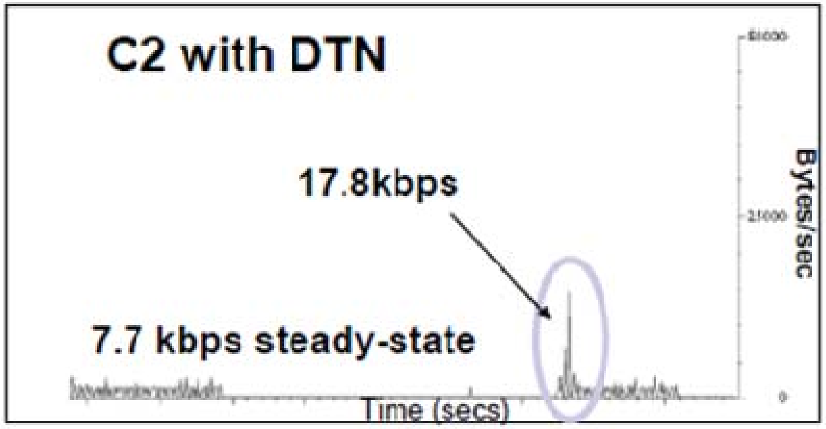

Figure 16. Typical BW consumption with DTN (From [32])

In this case, DTN creates almost 75 percent reduction in bandwidth usage as it uses hop-to-hop management of the transfer and ensures that the server's perception of the client state is accurate at the time of content delivery.

4. Wireless Cognitive Content-Based Networks With DTN

Wireless is an environment where bandwidth is a limited and costly resource in terms of spectrum, equipment and energy. Current networking practice is to keep network and application layers independent. Disruption Tolerant Networking is performed using a bundle (as previously mentioned) that internally groups metadata and data, and provides a context for any node that processes it. Access to network contents is performed based on descriptions of content, rather than specification of the end node at which it is located. This is the initial step in the process to develop a content-based network. The key characteristics of the DTN architecture under evaluation by the DARPA DTN program are [32]:

- The use of caches, in order to retain opportunistic copies of content at all nodes (sources, recipients or routers) that receive or process bundles, if the transmission is interrupted.

- Introduction of “late binding” mode, where requests for, or provision of information is not resolved to a specific network or node address, instead the request or content is “launched” in the general direction of the ultimate destination, and the specific destination is determined as the bundle approaches the destination region.

The advantages of cognitive wireless networks are obvious. First, the organization of information is dynamic and interactive with the network organization, and the users’ behavior is inherently correlated. Moving the necessary information only once preserves bandwidth. Second, network operational details do not need to propagate through the network or be available at the time the information is generated or requested. Disconnected nodes can address content and have content directed to them while operational data and other meta-data need only be distributed locally within a DTN region, rather than globally [32]. Based on this perspective, a realistic model for a network would assume a high-speed edge, rich in internal connectivity and bandwidth resources and a lower speed in the core, instead of the opposite. In fact, as shown in Figure 17, the model of a wireless network must shift from a collection of clients of a core application to self-contained and self-reliant networks with considerable inherent capability [32].

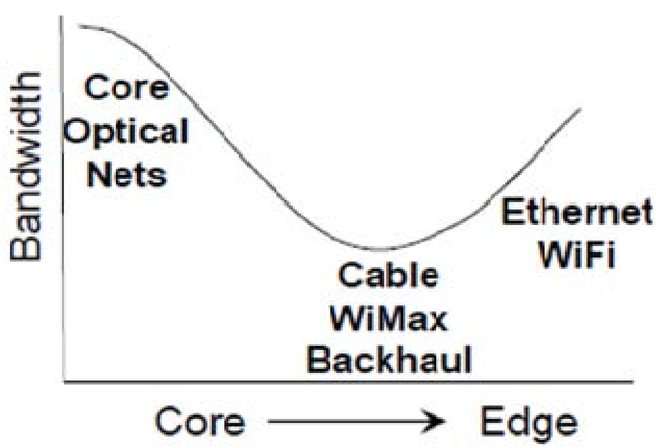

Figure 17. Alternative views of core and edge (From [32])

If the intra-edge bandwidth is plentiful, the performance constraint lies in linking the connected edge to the connected core. According to DARPA DTN research, this can be achieved with distributed peer content caching, and evolve to peer-to-peer architectures that are rich in range of content and have less backhaul bandwidth needs.

5. DTN for Touch Networking

The DTN concept has been applied fragmentarily in the last decade, but it has the unique potential to be integrated into a single pervasive network service. Of course, the Delay/Disruption Tolerant Network will not be a future internet itself; however, it can be an important part of it. From a military point of view, DTN can transform military communications in a profound way, with potential applications spanning a wide spectrum of DoD interests including tactical SA, strategic operations (i.e., intelligent content flow management), special operations, and intelligence (e.g., electronic drop boxes[9], and data mining[10]). Still, many research issues in DTN include DTN Multicast/Any cast Architecture, Routing, Security, Future Internet Component Technologies, Cognitive Radio, Software Defined Radio, and Active Networks. Networking-by-Touch can also benefit from the advantages of the DTN technology. Exploitation of soldier-collected information passed quickly through Networking-by-Touch interfaces that use DTN protocols to a higher-echelon command provide the possibility of more rapidly achieving SA across the force. Alternatively, DTN architecture may facilitate processing and dissemination of key data and knowledge by small squad leaders through touch interfaces. Application of DTN techniques to NbT nodes may potentially enhance battlefield awareness.

[9] A cloud computing-enabled scenario where one can upload files anonymously to an FTP server but not be able to see or download files that others may have uploaded, is often called a “drop box” (resembling a physical box with slot on top).

10 Data mining is the process of determining patterns, trends, relationships and associations in large data sets that are not so obviously declared in the raw data, collected by a great number of different sources.

D. NETWORKING-BY-TOUCH INTEGRATED INTO HUMAN AREA NETWORKS (HANs)

1. A Taxonomy of Wireless Networks

Wireless communication applies across a wide range of network types and sizes. Many wireless technologies exist and new variants appear continually. Wireless technologies are traditionally classified broadly according to network type, as the taxonomy in Figure 18 illustrates.

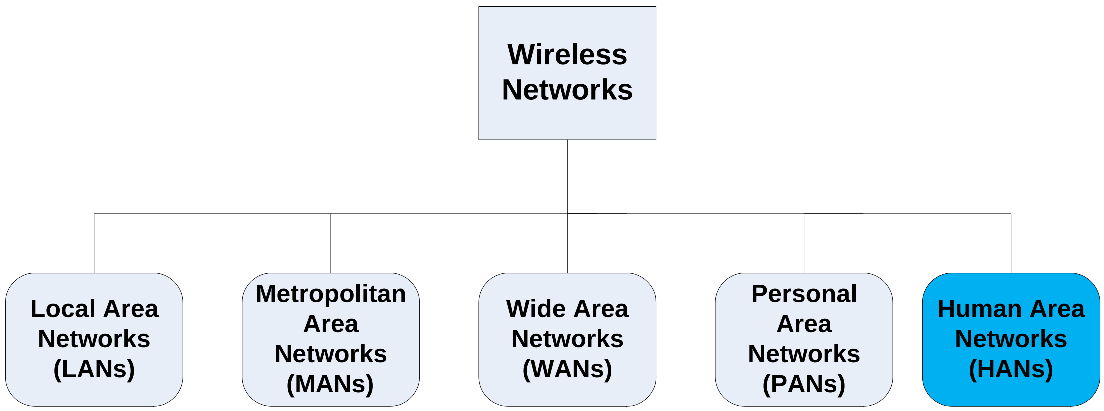

Figure 18. A taxonomy of wireless networking technologies

IEEE has standardized several Local Area Network (LAN) and Metropolitan Area Network (MAN) technologies. Wi-Fi uses the IEE802.11 standards with variants each assigned a suffix, such as 802.11b or 802.11g. Wireless LANs can be ad hoc or can use infrastructure architecture with access points; the frame format includes a Media Access Control (MAC) address for an access point as well as a MAC address for a router beyond the access point. In addition to LANs, wireless technologies are used for MANs and Personal Area Networks (PANs). The main MAN technology is known as WiMax, which can be used for backhaul or access. Wireless WANs use cellular and satellite technologies. The objective of PANs is to facilitate seamless operation among personal devices and systems, thus enabling every device in a WPAN to plug in to any other device in the same WPAN, provided they are within range of one another. PAN concept is described next, since it paves the way for the most intimate form of networking to date: the HAN, whose functionality is based on data transmission through the body due to the modulation of an electric field.

2. Wireless Personal Area Network (WPAN)

The Wireless Personal Area Network (WPAN), also known as in-home network, addresses short-range ad hoc connectivity among portable consumer electronic and communication devices centered on an individual’s workspace or being carried (see Figure 19) such as a wireless headset with a cell phone, for example. Connecting these devices with an intermediate network around the body rather than having several independent networks for data exchange, increases computational resources and storage capabilities, and it facilitates Input/Output (I/O) functionality. WPANs provide high-quality real-time video and audio distribution, file exchange among storage systems, and cable replacement for home entertainment systems. UWB technology emerges as a promising physical layer candidate for WPANs because it offers high-rates over short range, with low cost, high power efficiency, and low duty cycle. WPANs, usually operating at around 2.4 GHz, provide sufficient range (i.e., a few to 10 meters) for intrapersonal communication of multiple, small, inexpensive, low power-consuming personal electronic devices. Additionally, it permits connections to higher-level networks (e.g., WLAN or WiMax). Even though PANs can be wired via USB or FireWire, they are more commonly networked wirelessly through Infrared Data Association (IrDA), IEE 802.11, Bluetooth IEE802.15.1a, Ultra-Wideband (UWB) IEE802.15.3a, Zigbee IEE802.15.4, or Radio Frequency Identification (RFID).

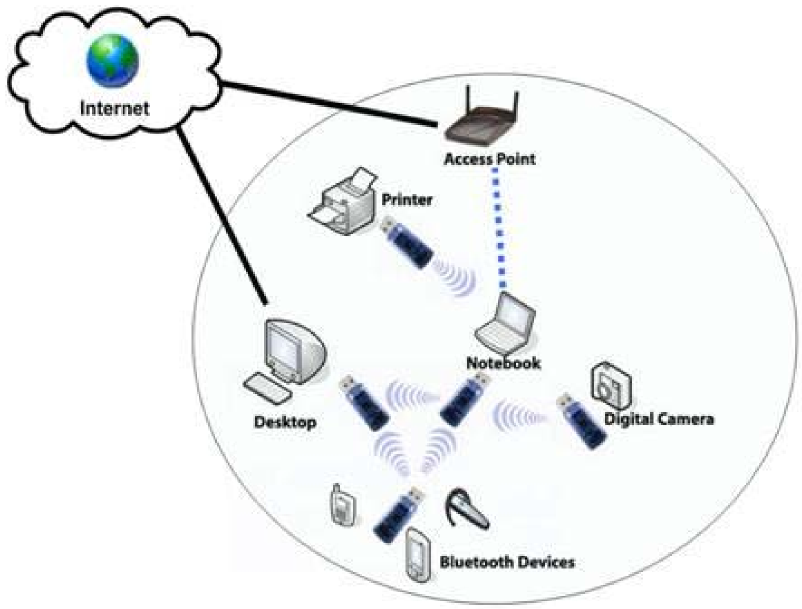

Figure 19. Wireless Personal Area Network (From [39])

3. Wireless Body Area Network (WBAN)

The Wireless Personal Area Network (WPAN), whose devices (i.e., wireless sensor network nodes) are mounted on the human body, is popularly known as Wireless Body Area network (WBAN). Recent technological advances in integrated circuits, wireless communications, and physiological sensing have boosted the development of miniaturized, lightweight, ultra-low power, intelligent monitoring devices. A number of these devices can be integrated to form a WBAN. These networks have gained importance for health and wellness monitoring to sense or monitor biometric parameters and vital signs such as body temperature, activity or heart rate, glucose levels, etc. [40]. As a body centric network, the Wireless Body Area Network (WBAN) consists of body-related network elements, such as the personal terminal, the wearable or body embedded sensors and network devices, as depicted in Figure 20.

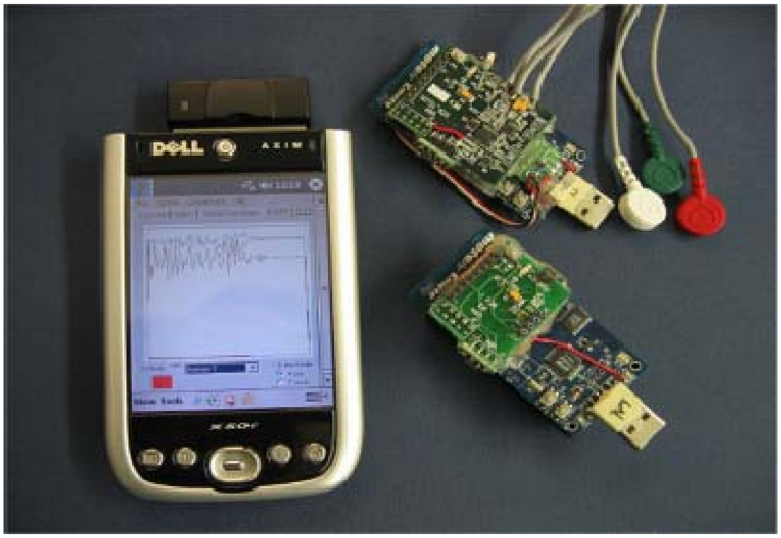

Figure 20. Prototype WBAN. From left to right: Personal Server with Network Coordinator, ECG sensor with electrodes, and a motion sensor (From [41])

The basic concept of WBAN involves passing the data flow from human body sensors via a series of WBAN modules onto a main body station that consolidates all data streams. Then, it transmits the data to a home base station or a Personal Digital Assistant (PDA) or mobile phone, from where data is forwarded to outer networks or a backbone network. A typical WBAN prototype for medical services is shown in Figure 21. The permissible communication distance of WBAN from the main body station to the home base station is about 2~5 meters.

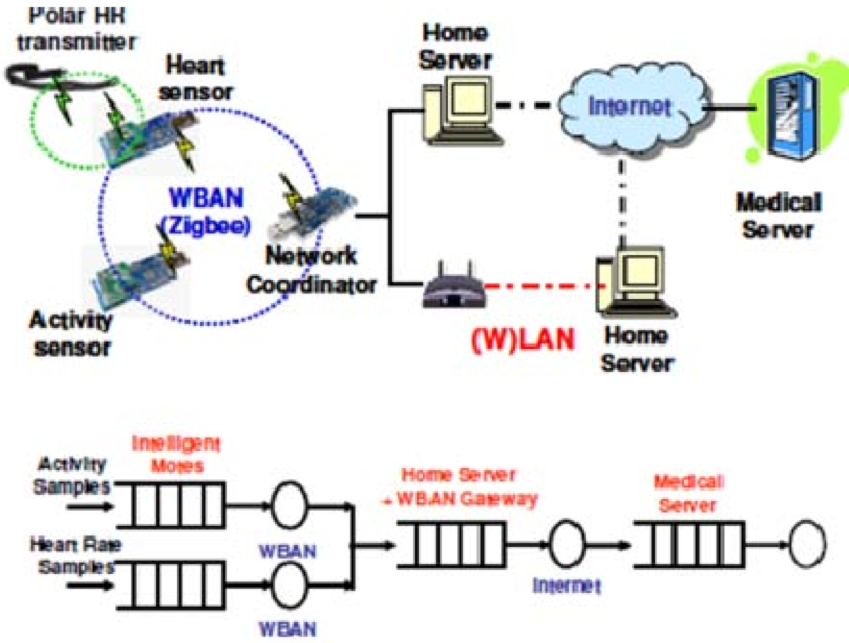

Figure 21. WBAN Prototype and Data Flow (From [42])

A typical BAN has a set of 30 to 50 wireless sensors with a low transmit power constraint. In addition, the wireless channel seen by a wireless node is unique when mounted on the human body. It has been shown [42] that UWB supports reliable connectivity at low transmission power for body mounted wireless nodes. Furthermore, UWB supports co-existence with other wireless networks and enables a higher data exchange rate, so when a large number of nodes are placed in close proximity, the BAN operates in a multi-user interference limited environment.

4. Human Area Network (HAN)/Human Body Network (HBN)

The advances in the area of microelectronics and nanotechnology have led to the miniaturization and microminiaturization of computers. The future network, the Human Area Network (HAN), may be the integration of human intelligence and a computer processing capabilities with these evolved technologies. The HAN is a wireless communication network that allows electronic devices on/near the human body to exchange digital information through interfaces permitting near-field electrostatic coupling; HANs distinguish themselves through their direct, deliberate integration with human users [29].

Imagine the scenario where a tiny wireless-enabled microprocessor, inserted into a human body communicates with outer network-enabled devices (e.g., mobile phones, computers or positioning systems) at a short distance. This chip may be powered by the energy of the master (e.g., blood pressure, heartbeat, or rapid arm movements) while wearing a nanofiber electricity-generating shirt [42]. The chip contains private information about the master such as name, ID card or telephone number, blood type, gene sequence, hobbies, or even bank account number [42]. Each person with the same equipment becomes a node of the network. This is the Human Body Network (HBN).

The HBN is the integration and evolution of modern concepts of the Wireless Body Area Network (WBAN), the Wireless Personal Area Network (WPAN), the Wireless Sensor Network (WSN) and any form of wireless wearable networks. A key parameter to its function is a unique identification that each node needs, called the Human Body Identification Code (HBIC) [44], to be able to distinguish itself from other nodes. This is similar to the Media Access Control (MAC) address used in the Local Area Networks (LANs), the Internet Protocol (IP) address used in the Internet, or the Subscriber Identity Module (SIM) used in cellular phones. The chip-embedded unique identification data equipped in the human body represents not only the communication device identification, but also the person using it. Ultimately, this becomes the integration of the hardware address, the transportation address and the user identity [44]. With the use of the HBIC, the existing security identification methods such as password, fingerprint or iris recognition are now obsolete, since people know exactly with whom they are interacting.

5. HAN – Relevant Wireless Short-Distance Technologies

a. Near Field Communications (NFC)

Imagine a scenario where a fan on his way to attend a game makes his parking payment by touching a parking tag with his mobile phone and then breezes through the front gate of the stadium, paying for his ticket by waving his cell phone near a Point-of-Sale (PoS) reader. On the way to his seat, he downloads wallpaper or information to his handset by touching it to a smart poster of his favorite player [45]. After the game, he enters the underground metro and pays the train fare in a fraction of a second by touching a payment IC card to the card reader while walking through the gate. This is a simple touch transaction on every pass. Heading towards a downtown fast food restaurant, he has dinner and pays for it at another PoS reader by using electronic coupons stored in his phone.

For the military environment, a similar scenario would involve, for example, the team leader of a reconnaissance squad that receives his Rescue and Search (R&S) mission statement and tactical information (e.g., imagery, GPS feeds, etc.) by touching tags with his NFC-enabled PDA on one of the nearest NFC control points located in his Area of Operations (AO). Prior to receiving this information, the soldier is granted automatically a context-sensitive electronic access for specific need-to-know information from this NFC control point that is serving many different types of users with different access rights and classification levels. In addition to that, while performing face-to-face coordination before departing for the mission, critical information is transmitted via touch to his fellow teammates.

The previous scenarios are based on NFC technology, a tool that allows interaction intuitively and through increasingly electronic environment using an easy-to-use short-range wireless technique that has been jointly developed as an open standard by Philips Electronics and Sony Corporation in late 2002. NFC is a combination of contactless identification and interconnection technologies that enable short-range intuitive and simple communication between NFC-enabled electronic devices, such as mobile phones, smart cards, PDAs, computers and payment terminals via a fast and easy wireless connection, simply by touching or bringing them close [46]. NFC operates in the 13.56 MHz frequency range over a distance of typically a few centimeters (compared to Bluetooth's 10meters and Wi-Fi's 100meters) due to the magnetic inductive coupling principal that works only at short distances. It combines the functions of a contactless reader, a contactless card and peer-to-peer functionality on a single chip. Data transfer is of a maximum of 424 Kbps, compared to Bluetooth's 3 Mbps and Wi-Fi's 54 Mbps. NFC is both a "read" and "write" technology. A simple wave or touch can establish an NFC connection, which is then compatible with other known wireless technologies such as Bluetooth or Wi-Fi.

NFC technology has been evaluated and trial-used in several application domains. The possibilities are endless [47]. One of the largest efforts on piloting NFC technology in the European Union is The SmartTouch project that explores the use of touch-based user interaction to demonstrate new and innovative mobile services in City Life, Home, Wellness and Health, Security and Privacy [48]. From the military point of view, one major drawback for the extensive use of NFC military applications, apart from the limited bandwidth, is the inadequate protection against eavesdropping and the vulnerability to data modifications, which is currently a topic for further research.

b. Intra-body Communications (IBC)

There is no doubt that with the continuous miniaturization, human society is entering an era of the so-called ubiquitous computing environment where many computers serve each person everywhere in the world, and everything is networked. In order to have Human Area Networks fully feasible, it is essential to share data, not only among our own personal computers, but also among peripheral computers. With the solution of Intra-body Communication

(IBC), ubiquitous services based on human-centered interactions are enabled, therefore, more intimate and easier to use. IBC is a novel communication technique that uses the human body as the transmission medium for electrical signals. The human body contacts a very small current to body-mounted devices that are modulating electric fields, and to the environment, facilitating a communications path for transmitting/receiving low frequency radio signals [29]. The exchange of data is realized unconsciously by the communicators, with the actions of touching or stepping, while they are clearly aware of connection. In addition, data transmitted through the human body eventually escapes through the feet into the ground (Figure 22), thus minimizing the chance of intercept and, thereby, providing secure transmissions [49].

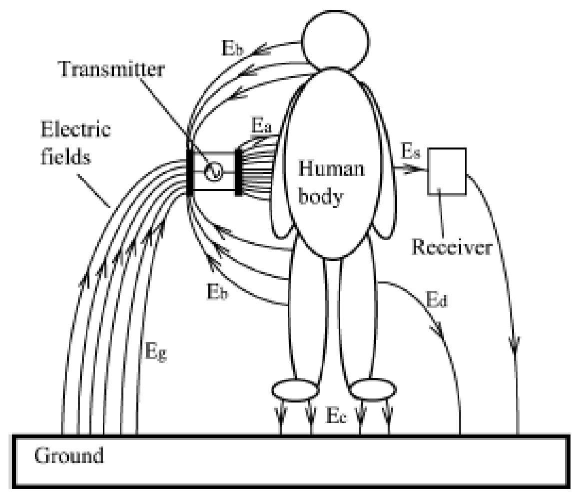

Figure 22. Electric-field model (From[49])

Within the Personal Area Network (PAN), a first data communication using the body as medium was realized via electrical coupling [50]. Using a fixed carrier frequency for signal propagation through the human body, several attempts were made to model the human body as an electrical channel [51]. Further research with the use of electro-optic sensors increased the usable frequencies to several MHz [52]. With this technique, an electro-optic sensor of extremely high input impedance suitable for the detection of small and unstable electric fields produced by the human body is implemented on the transceiver. This transceiver enables IEEE 802.3 half-duplex communication of 10 Mb/s through a person's body (even through clothes) an operating range of about 150 cm between the hands (Figure 23). Additionally, it enables intra-body communication between two persons by a handshake [49].

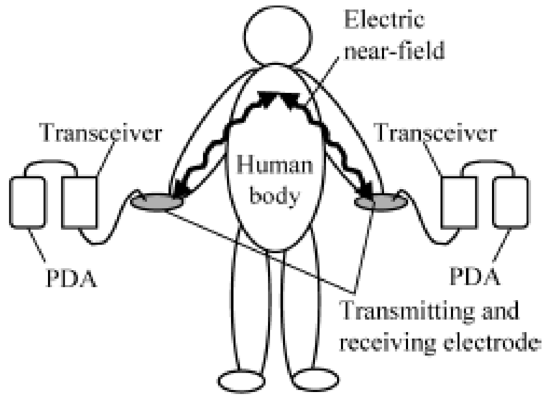

Figure 23. Intra-body communication (From [49])

The most recent approach for wireless intra-body data transmission between sensors is capacitive and galvanic coupling. It is suitable for ultralow-power wireless body local area networks over a frequency range from 10 kHz to 1 MHz [53].

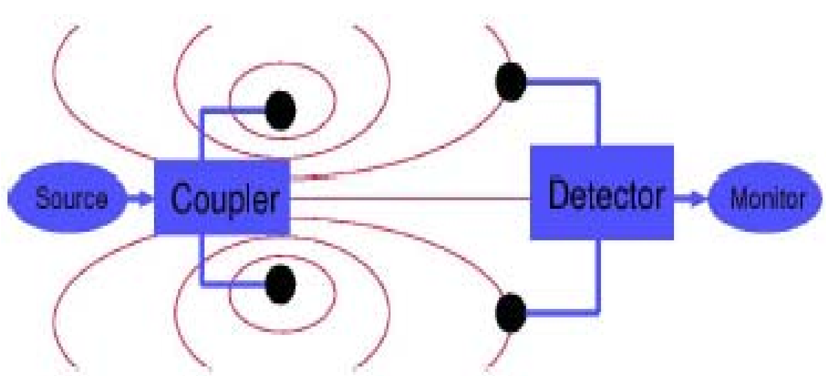

Figure 24. Concept of galvanic coupling using the body as electrical transmission (From [53])

The concept of galvanic coupling is based on the signal transfer that is established between the transmitter and receiver units by coupling signal currents galvanically into the human body. The signal is applied differentially over two transmitter electrodes and received differentially by the two receiver electrodes. The transmitter establishes a modulated electrical field that is sensed by the receiver as shown in Figure 24.

One of the marketable IBC-driven products patented by the Nippon Telephone and Telegraph (NTT) of Japan is RedTacton [54]. This innovative instantiation of IBC technology triggers touching, gripping, sitting, walking, stepping and other human movements for unlocking or locking, starting or stopping equipment, or obtaining data (see figure 25). It enables one-to-one services tailored to the user's situation and tastes based on the attribute information received by the RedTacton receiver. Conversely, attribute information recorded in the RedTacton device is sent to the touched objects. Duplex, interactive communication is possible at a maximum speed of 10Mbps. Because the transmission path is on the surface of the body, transmission speed does not deteriorate in congested areas where many people are communicating at the same time.

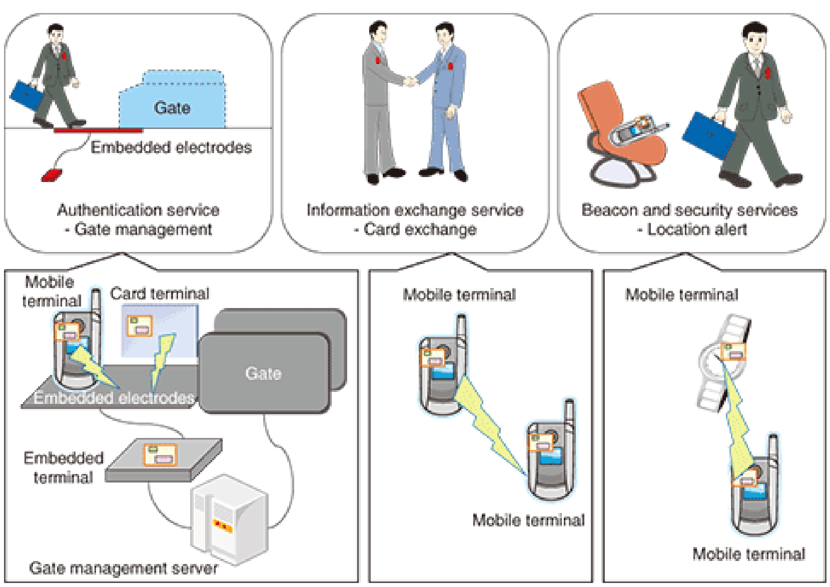

Figure 25. Examples of services enabled by RedTacton (From [55])

E. OVERVIEW OF EXISTING NbT SYSTEMS

Tactile interactions provide important sensory modalities that are exploited in many types of practical applications. This section summarizes the existing experimental implementations and market trends of the HAN concept based on tactile modality and touch sensing. Additionally, it presents an overview of the state-of-the-art in tactile display applications and software.

1. Tactile Displays

A tactile display is a human-computer interface that utilizes tactile-only signals to reproduce the parameters of an object, such as shape, surface texture, roughness and temperature. The human operator has a finite ability for processing a plethora of information in cases where visual and/or auditory channels are overloaded and information is either impaired or unavailable. Examples of these cases include [56]:

• Operators who work at the limits of their visual and auditory processing capacity, such as pilots.

• Operators whose visual or auditory attention focuses on a specific area of interest, such as dismounted soldiers who want to focus on the environment and possible threats.

• Operators who work in a visual or auditory deprived environment, such as remote operators, virtual environment users, divers in dark waters, drivers of fast boats, or fire fighters.

• Operators who work under conditions that require the minimization of the transmission of light or sound, as during night or covert operations, such as soldiers of Special Operations Units.

Previous research [57] has shown that providing information by an underused sense, such as the sense of touch, can improve the cognitive processing of that information while reducing the probability of cognitive overload. Tactile displays have shown the ability to provide improved situation awareness to operators of high performance weapon platforms and to improve their ability to spatially track targets and sources of information. Tactile displays can reduce perceived workloads by their easy-to-interpret, intuitive nature and can convey information without diverting the user's attention away from the operational task at hand [16]. There are currently four main applications for which tactile displays have a great potential for military needs; orientation, navigation, communication, and training and simulation.

a. Orientation

Spatial orientation is the ability of an individual to realize his position in space, and to detect and determine relative position and motion of targets. Situation awareness can be improved by displaying the locations of moving entities or points of interest through tactile displays, and develop an information presentation that allows conveying the direction and the distance of surrounding objects, places, or entities. Tactile displays can also present information for the direction of wingmen, enemy contacts or lines of attack to support spatial information/situation awareness. Spatial disorientation is a tri-service problem primarily effecting aviation, but can also occur with divers under water and with astronauts in conditions of microgravity.

b. Navigation

Tactile devices can provide directional cues for navigation through space. These navigation cues include waypoint direction, no-go areas, obstacle avoidance cues, or collision avoidance information. For example, tactile cues could enable a pilot to perform precision hovers in poor visual environments, such as foggy conditions, or to inform him of the bearing of a missile locked onto the aircraft, or the direction of an emergency rendezvous location. The tactile navigation displays are designed to give information on course errors and course correction instructions. Waypoint navigation using tactile cues was demonstrated in a variety of unfamiliar environments [58]. It applies the sense of touch to guide the user on a planned route. Research includes divers operating underwater at

NAMRL, high-speed boats at QinetiQ, automobiles and aircrafts at NAMRL and at TNO. QinetiQ [59] developed a new underwater navigation and search system for Mines Counter Measures (MCM) operations, particularly in shallow littoral waters. The QinetiQ Diver Reconnaissance System (DRS) is based on a handheld swim board concept (see Figure 26) and incorporates a fully functioning microprocessor, which can receive various sensor data and log and display mission information. The diver has full control over the system functions by means of underwater mouse controls fitted into the handles. The diver is able to navigate in a pre-determined search area to an accuracy of approximately 0.5m. Engineering Acoustics, Inc (EAI) has developed tactors capable of being fitted inside a wetsuit for working underwater, and has demonstrated the effectiveness of tactile displays for underwater operations [60]. The intent of the testing was to evaluate the feasibility of using tactor technology for steering indicators in an underwater environment.

Figure 26. Diver Navigation System (From EAI Inc)

An additional diving application for tactile displays is to provide enhanced situational awareness for mini-submarine (e.g., U.S. Seal Delivery Vehicle (SDV) operations). This could include navigation, depth control and obstacle avoidance warning [56]. In addition, NASA has conducted research into the use of tactile displays in microgravity using parabolic flights, and further study into this environment is carried out on the International Space Station by researchers from TNO Human Factors Research Institute of the Netherlands [56].

c. Communication

Soldiers on the battlefield have lots of sights and sounds to keep up with (i.e., combatant devices that have visual displays or provide auditory alarms) so they do not need more visual or auditory prompts. Sometimes the only communications channel that remains underutilized is touch. Researchers have found that people respond faster and more accurately to tactile communication compared to surround-sound audio cues [61]. Most of the research findings show advantageous uses for tactile communications, especially for basic communications. These cases include: bright light environments where visual display screens are difficult to comprehend, high-noise environments where aural communication is difficult, battlefield patrolling scenarios where vision is required for primary tasks, covert operations where visual and/or audio signatures are unacceptable, and night-time operations where visual displays disrupt night vision adaptation [61]. Tactile cues are also highly effective for directional warning and attention allocation by communicating the direction of potential threats, initiating ground proximity warnings or indicating areas of (visual) interest.

A study conducted by the U.S. Army Research Laboratory (ARL) with a state-of-the-art tactile prototype display developed by the University of Central Florida (UCF) evaluated infantry soldiers' abilities to interpret and respond to tactile commands [62]. Results demonstrated that soldiers performing individual movement technique (IMT), while simulating a combat patrol, were able to receive, interpret, and accurately respond to the tactile commands faster than the information passed by conventional hand and arm signals from leaders in front of and behind. Soldiers were able to focus more attention on negotiating obstacles and on area situational awareness. In another experiment conducted by the USARL [63], the reaction times for soldiers firing at targets based on (a) auditory commands, (b) auditory/visual commands that required decoding and (c) tactile only commands were 2.1 seconds, 4.2 seconds and 1.29 seconds, respectively. In addition, researchers from the U.S. Army Natick Soldier Center and the U.S. Army Research Institute of Environmental Medicine used the tactile modality as a secondary communication source, to the visual and auditory modes of communication, to examine the effects of movement and physical exertion on vigilance [64]. Results showed that while traversing a course with obstacles, participants covered less distance when responding to tactile signals than to auditory signals.

The Appendix, describes the basic coding schemes and tactile communication procedures for intuitive signals perceived by soldiers via tactile displays—in other words, a simple tactile lexicon that conveys a sampling of standard Army hand and arm signals that are converted into tactile cues. This type of tactile language sets the basis for a local communication network between soldiers wearing vests or belts, operating in relatively close proximity under low-visibility or silence-essential conditions.

d. Training and Simulation

Virtual reality (VR) and motion-based simulation have become essential parts of training the modern soldier. Computer generated graphics and sound can submerse the user in a very realistic synthetic environment by reproducing or simulating perceptual cues of remote or virtual worlds (e.g., in controlling Uninhabited Military Vehicles (UMVs)) and in training and simulation [56]. In some VR environments, a user can actually move limbs through solid objects and can only use visual cues to determine his proximity to objects, even if touching them. Tactile displays can add the sense of feel and provide a more realistic physical response in training situations. For simulated environments, tactile cues offer the potential of a greater sense of presence and improved task performance. In the medical field, computer simulations with haptics are possible to provide precise representations of human physiology with the simulation of different patient types. The combination of visual and haptic feedback can be very valuable when training (e.g., field surgery operations). The operating conditions in a battlefield may be poor, with lots of dirt and blood in the operating area, so the sense of touch with realistic feedback from the haptic device is more important than the sense of sight.

Despite this potential for VR training applications, relatively little research has been done in this area. Nevertheless, the use of haptic feedback resulted in improved training effectiveness, even though the sensations provided did not replicate those experienced during actual examinations [56].

2. Tactile Situational Awareness System (TSAS)

Two are the main drivers for developing tactile display applications: the notable necessities to provide Spatial Disorientation (SD) countermeasures and solutions to the threats of sensory and/or cognitive overload of the individual's capacity to process the information provided in current man-machine interfaces. The variety of tactile displays such as the TSAS described in this section, range from a single vibrating element (e.g., mobile phone vibration mode) to matrices of elements covering the torso, the waist or the head of a pilot, soldier, diver, or other operator.

a. Vest Garment

Indicative examples of this matrix display are the Tactile Torso Display (TTTD) (see Figure 27) developed and evaluated by the TNO and the Tactile Situation Awareness System (TSAS) (see Figure 28) of the U.S. Naval Aerospace Medical Research Laboratory (NAMRL) [65], [66]. These applications provide intuitive three-dimensional spatial information to minimize spatial disorientation and to provide navigation and threat/targeting information to operators of various military platforms.

Figure 27. TNO Tactile Torso Display (TTTD), Consisting of a Matrix of Vibrating Elements Inside a Multi-Ply Garment Covering the Helicopter Pilot’s Torso [From [60])

The TSAS consists of tactile stimulators (tactors) (see Figure 29) on the torso and limbs of the body that relay processed information from a variety of sensors to the operator [66]. Two types of tactors are currently available: pneumatic (air pulsed) and electromagnetic (magnet and electrical coil).

Figure 28. Pneumatic type TSAS for Military Aircraft (From [67])

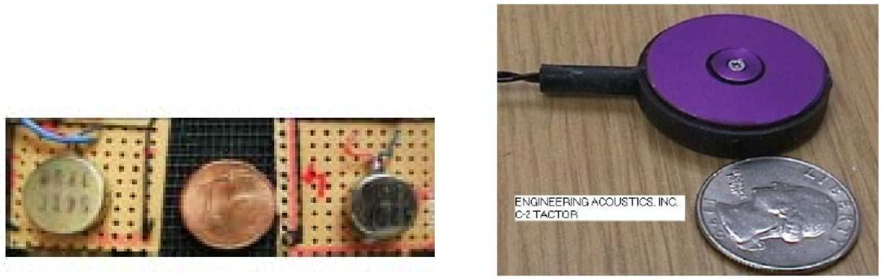

Figure 29. Left: Samsung A600 and A400 vibrator motors (From [68]) Right: EAI sample C2 Tactor with size comparison (From [62])

The TSAS was also developed for the Special Forces (TSAS-SF) [69] and pilot tests for ground navigation. Testing results show improved performance and mission effectiveness, and reduced workload and fatigue rather than with only a visual display.

b. Head-Mounted Tactile Display (HMTD)

The head can also be used as a communication tool for providing tactile alerts to the soldier in order to relieve sensory overload on the visual and auditory channels. A four-tactor, circular head array prototype as depicted in Figure 30, is recommended for a HMTD design to test soldier performance, according to research by the U.S. Army Research Laboratory [70].

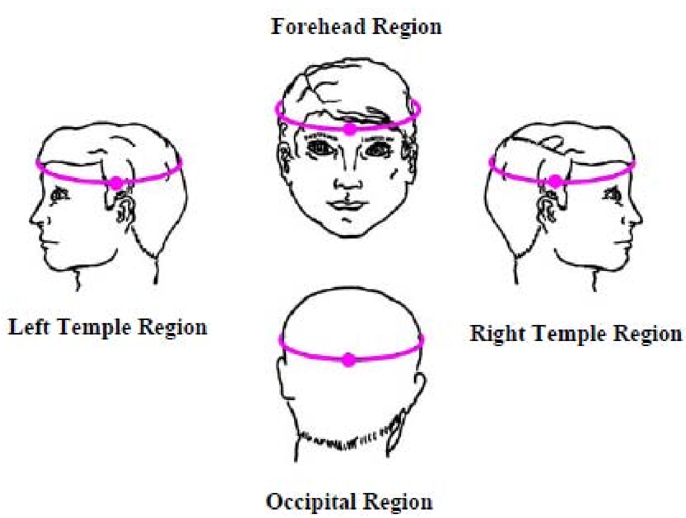

Figure 30. Diagram of the proposed HMTD: four-tactor, circular head array [From 70]

The forehead, occipital, and temple regions of the head are most sensitive to vibration stimulation. The reasonable frequency for the optimal perception of vibration on the head appears to be 32 Hz. Above 150 Hz, user discomfort becomes a serious issue [70]. The vertex (i.e., uppermost surface of the head) and the temples (the side of the head behind the eyes) are the head locations that are most suitable for vibration stimulation or head tactile communication [70].

c. Tactile Belt

A tactile belt is an array of tactile actuators on a belt. By stimulating sites around the waist, the user can comprehend directional cues. For example, a vibro-tactile stimulus at the abdomen is interpreted intuitively as “in front of user.” U.S. Army Research Laboratory (ARL) scientists are currently working on a tactile belt for the torso designed for infantry soldiers to aid in navigation on the battlefield [61], [63]. This belt-type tactile display (see Figures 31, 32) conveys the necessary information non-visually, non-intrusively, and hands-free [68]. The same tactile belt display is used for research at the University of Central Florida to test the ability of USN Seals under physiological stress, similar to what the actual combat, and augment underwater navigation.

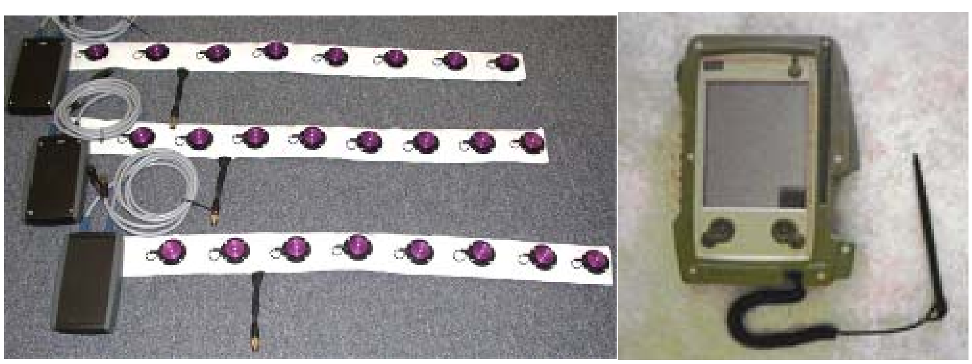

Figure 31. Left: Tactile display belt components with Tractor Components Box (TCB). Each box includes a wireless Bluetooth receiver and the controlling circuitry. Right: Advanced robotics controller (lightweight) PDA that remotely sends the selected signal to the TCB to trigger the tactile message (Developed by Massachusetts Institute of Technology (MIT).

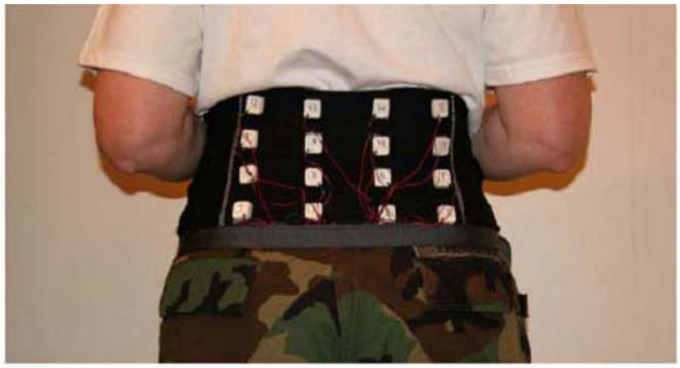

Figure 32. Tactile back configuration (From [63])

3. Multi-Touch Tabletop Display System

This hardware platform enhances the availability of next generation multimedia contents utilizing the interaction between the user and information system to manipulate the contents naturally by recognizing the motion of the user's hands and the contact between the hands and the display [71]. This technology engages in interaction of human, computer, physical objects and displayed objects to embody context awareness. The multi-touch display is capable of tracking fingertip movement and counting the number of fingertips that the user is employing for interaction by using hand gesture instruction, multi-touch instruction, and combined hand gesture and multi-touch instruction. (Figure 33)

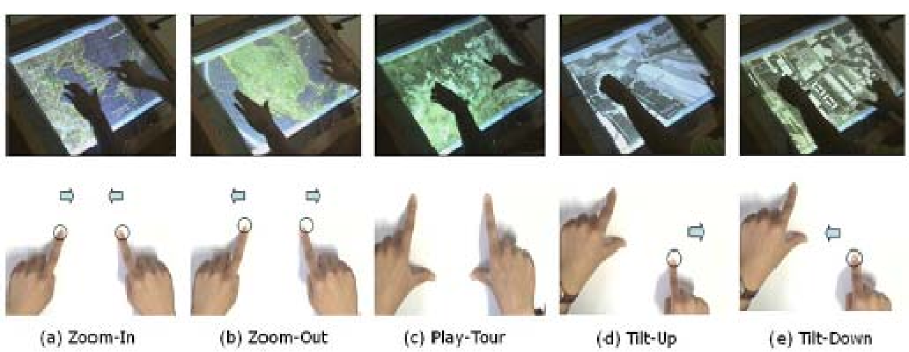

Figure 33. System operation with two-handed instruction set. (a) Zoom-In (b) Zoom-Out (c) Play-Tour: both hands are fixed for a few seconds. (d) Tilt-Up: fingers of left hand are fixed. (e) Tilt-Down: fingers of left hand are fixed (From [71])

A multi-touch tabletop displays can help cooperative interaction of multi-users as a medium of communication. The natural direct manipulation of physical objects creates an augmented reality. The system consists of two beam projectors, diffuser film, infrared cameras, and a large acrylic screen with an attached infrared LED [71]. When the fingertips touch the surface of a waveguide medium, the condition of the total internal reflection[11] is disturbed; therefore, a scattering occurs along the surface where FTIR happens and detection of discrete light through an infrared camera with an attached IR pass filter installed under the screen can be made. Hence, the position of the homogeneous point that finger has touched is recognized. In a recognition process, gesture commands are analyzed by comparing with predefined gesture instructions according to the number of contacted fingertips, Euclidean distance, and angles between two bright spots of FTIR.

4. Pervasive Health Monitoring – Telemanipulation

As defined in the annual pervasive health conference held in Helsinki in 2007, pervasive healthcare is health monitoring, emergency management, healthcare data access, and ubiquitous mobile telemedicine to anyone, anytime, and anywhere by removing location, time and other restraints while increasing both the coverage and the quality. Of course, wireless networking solutions like wireless LANs, ad hoc wireless UWB networks, cellular/GSM/3G infrastructure-oriented networks and satellite-based systems have prominent roles in remote healthcare applications. Along with those telemedicine methods, haptic actions are often used in open surgery because visual action is not possible. The surgeon often depends on haptic feedback when identifying blood vessels under other tissues, etc. Tactile display technology is applicable in this area with the use of telemanipulation, a remote palpation system that will convey tactile information from inside a patient's body to the surgeon's fingertips during

11 Frustrated Total Internal Reflection is also a total reflection obstacle phenomenon that is used in robot sensor technology. Frustrated Total Internal Reflection (FTIR) Sensing Technique principle has been used mainly in the biometrics community for fingerprint extraction since the 1960s.

minimally invasive procedures [16]. One specific application, called Teletaction [72], allows for remote sensing and display of tactile information (i.e., contact properties) through sensor arrays to the surgeon. To provide local shape information, an array of force generators can create a pressure distribution on a fingertip, synthesizing an approximation to a true contact. In addition, with the use of gloves that provide tactile feedback, two individuals in different locations could jointly move or manipulate/modify virtual objects and “feel” the forces applied on the object by the other individual or object.

Other than the medicine field, another potential for the use of telemanipulation is the control of real objects from a remote or otherwise detached location while providing tactile feedback to the user (e.g., a set of robotic arms for disarming bombs and mines from a safe and distant location). This would allow the human to feel the structure, wires, tools, etc., in his/her hands, virtually, to manipulate the bomb components more easily while maintaining safety [56].

5. Entertainment and Educational Applications

Adding a tactile interface to computer animation allows end users to interact physically with game environments—i.e., to feel the recoil from a weapon, to encounter turbulence in flight simulation, or walk into a physical wall. Several software applications have been developed for entertainment providing sensory enhancement. Tactors can simulate 3-D movie or gaming experience sensations from electrical shock and bee stings to bullet impacts. In the videogame industry, tactile force feedback has become a relatively standard feature. It is incorporated into the controllers of several home video game consoles including Sony’s Playstation 2, Nintendo’s GameCube and Wii, and Microsoft’s X-Box and X-box 360.

6. Tactile Displays Embedded in Consumer Electronics (Touch-Entry Devices) and Wearable Devices

Today, user-machine interaction is supported by various ergonomic designs; currently, popular input and output devices such as a keyboard, a mouse or a trackball cannot satisfy users when quick action is required of their task. Touch-entry devices, however, can create a faster response times for the users than conventional I/O devices and produce intuitive interaction with the machine interface. A wide variety of Touch-entry implementations like touch panels or touch screens are used today within the HAN environment. They play a prominent role in the design of digital appliances such as personal digital assistants (PDAs), satellite navigation devices, mobile or smart phones (like I-Phones), and video games [73]. With the rapid growth of sophisticated mobile applications, smartphones equipped with identity recognition and encryption software and enhanced communications capabilities for remote areas, could become a valuable asset in the U.S. military’s battlefield arsenal. Reuters reports that Raytheon is currently developing the Raytheon Android Tactical System (RATS) software for Motorola and HTC mobile phones running Google's Android OS. This platform, among other capabilities, allows soldiers to interact as 'buddies' and enables them to track each others' movements on the battlefield, as well as help them identify potential enemies in a way similar to social networking sites, such as Facebook [74].

Tactile mice, designed to allow the visually impaired to navigate through a computer screen, provide tactile feedback to the user's fingertips and help to recognize graphic shapes, text, maps, pictures, and art through touch. A new type of augmented Haptics, the SmartTouch application (see Figure 34) provides visual-to-tactile translation for the visually impaired [75]. The system is essentially composed of a tactile display and a sensor. When contacting an object, visual images captured by the sensor are translated into tactile sensations, such as a vibration or force by a tactile display through electrical stimulation (at the fingertip). Thus, a person not only makes physical contact with an object, but also may “touch” the surface information of any modality.

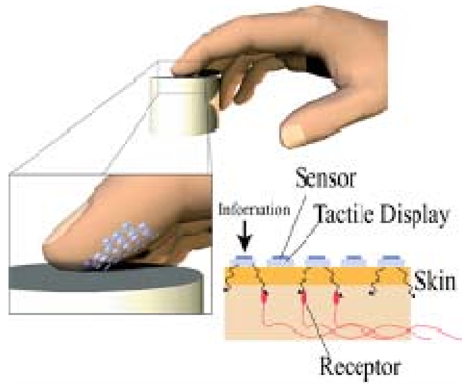

Figure 34. SmartTouch: A new functional layer of skin composed of a sensor and tactile display (From [75])

Tactile interfaces can also provide a channel for communication through comfortable and enjoyable interaction with the miniature handheld or wearable computing devices used in today’s world. Some of these applications include navigation notification through touch, and the use of gestures to interact with the device. Certain marketed tactile interface designs are:

(a) the Touch Engine [76], a tactile apparatus, which is embedded in Sony PDA touch screen enhancing its basic GUI elements with tactile feedback, whereas different tactile sensations are associated with various GUI elements, and

(b) the ComTouch [77], a vibrotactile device sleeve over the back of a mobile phone that augments remote voice communication with touch by converting hand pressure into vibration intensity.

7. Touch-Activated Interfaces

Recently, SONY developed a universal touch-activated interface, which instantly connects a wide variety of consumer (and non-consumer) electronic devices, called TransferJet™ [78]. This new close-proximity wireless transfer technology achieves high performance content sharing between these devices with low cost, high security, and simplicity of use. The end user, by placing his smart phone on a TransferJet™ target point connected to a host terminal, can send (push) or receive (get) any data file to/from a mobile/stationary terminal. Through a simple “touch” operation, he can access, retrieve, manage, and execute real time content in the same way as local files. Theoretically, TransferJet™ delivers a transfer speed of 560 Mbps or an actual speed of 375 Mbps, however, the first generation products that support it, launched in Japan this year (SONY VAIO F laptop and TX7 and HX5V digital cameras), have transfer rates of about 40 Mbps, due to software overhead in the PC and data processing.

III. PROPOSED MODEL DESCRIPTION

After having presented analytical examples, case studies and application scenarios of NbT implementation, this Chapter provides a conceptual framework for an adaptive networking model with DTN capability enabled by “touch” inputs/outputs performed in discrete time and space. It also describes the model’s interface with ad hoc mobile networks to serve small network-enabled units and discusses the use of social networking as a transmission medium for the model.

A. ADAPTIVE NETWORK IN DISCRETE TIME AND SPACE FOR SMALL UNITS

1. Social Networks With DTN as Transmission Medium

According to the vision of Mark Weiser, the father of ubiquitous computing, “the physical world will be connected with pervasive networks, and everyday devices will be able to sense their relationship to humans and to each other. Furthermore, these devices shall communicate with each other to organize and coordinate their actions.” [79] As such, HAN-enabled devices and peripherals employ a rich set of input modalities that recede into the background of human interactions, including touch, motion, vibration, pressure, radio, magnetic, etc. The ubiquitous nature of these technologies implies social networking capabilities. Social networking platforms allow users to share a rich set of contextual data via spontaneous, adaptive, self-configurative social network services by utilizing mobile devices (e.g., Laptops, Smartphone, PDAs) connected by wireless links (e.g., Mobile Ad Hoc Networks). Mobile Social Networks (MoSoNets) are sustained through information sharing of the users’ social network identities that are enriched by interactions, with the physical environment, with other people, as well as with nearby wireless devices. This physical hardware or wearable devices (e.g., a PDA) may gather information about user actions and environment. The contextual information is available for sharing with the social network, or it can be used to obtain pertinent information from the social network.

Apart from Web-based social networking reality, next-generation social networks shift the social networking services from centralized web-based to delay-tolerant, distributed storage for disconnected MANETs. In other words, there is efficacy to social networking services operating on Mobile Delay-Tolerant Networks (DTN) [38].

Prior research [38] to construct a Peer-to-Peer (P2P) infrastructure for social networking or communication services with DTN capability has suggested the top-down approach for network layers depicted in Figure 35

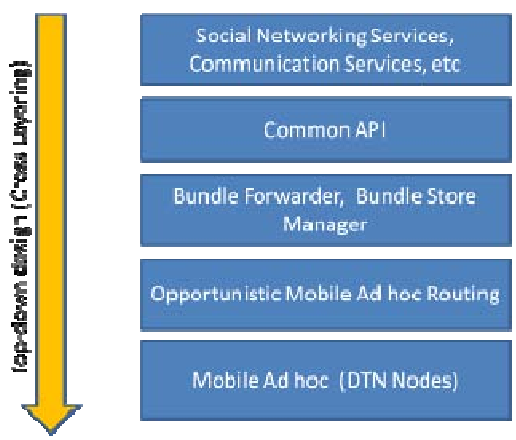

Figure 35. Cross-layer for Delay-Tolerant Social Networks ([After 38])

The HAN functionalities could maximize the effectiveness of social networks. Unfortunately, architecture and standards for HAN technologies or terminals do not yet exist nor is HAN implementation mature. Currently IEEE 802.15.6 is the working group assigned to explore potential BAN standards. This thesis will identify the critical components and the underlying architecture that integrates HAN/IBC possibilities into an imaginative end-state for mobile tactical networks.

2. Network Architecture

The U.S. Army Chief of Staff (COS), General Eric K. Shinseki, underlines his vision for the Future Objective Force:

> Operations will be characterized by developing situations out of contact. The integration of the human and technological enablers is critical to successful transformation to the Objective Force. [80]

It is reasonable to consider the NbT functionality a technological enabler towards the Objective Force, especially for the small-unit level of operations that encounter continuously developing situations. Small Unit Operations (SUOs) are typically related to a company size force; the smallest stand-alone ground tactical unit in an army. In the U.S. Army, companies consist of around four platoons. Each platoon consists of two or more sections, with each section composed of two or more squads. A squad leader controls two or more fire teams. Each fire team consists of approximately four soldiers. There are some underlying similarities between the social networking environment and small military units.

Small military units such as squad/platoon tactical level entities are similar to an adaptive network. They can be viewed as part of an overall MANET framework, consisting of distinct elements (nodes) that connect and communicate in discrete time and space through either the deliberate act of touch and/or tactile cues. These nodes in the MANET are either humans with HAN-enabled devices or stand alone HAN-enabled peripherals on secure space access points (i.e., predefined locations with HAN-enabled equipment). One of these nodes (for example the squad/platoon leader node) has the role of the master and the rest are the slaves. To sustain this kind ad hoc mesh network, the nodes connect automatically forming a self-organizing, self-contained communication system with inherent capability, and operate without the benefit of any existing infrastructure, and without a prior application protocol and/or a server. In other words, they ascertain the existence of nearby nodes, choose a topology, and establish routing to reach any other node. This is called a squad/platoon cluster with dynamic node entry and departure. Connectivity with adjacent and similar NbT network clusters, as well as with a wider MANET of nearby larger echelons of military units, is provided through the master node. A diagram of the proposed network topology is depicted in Figure 36.

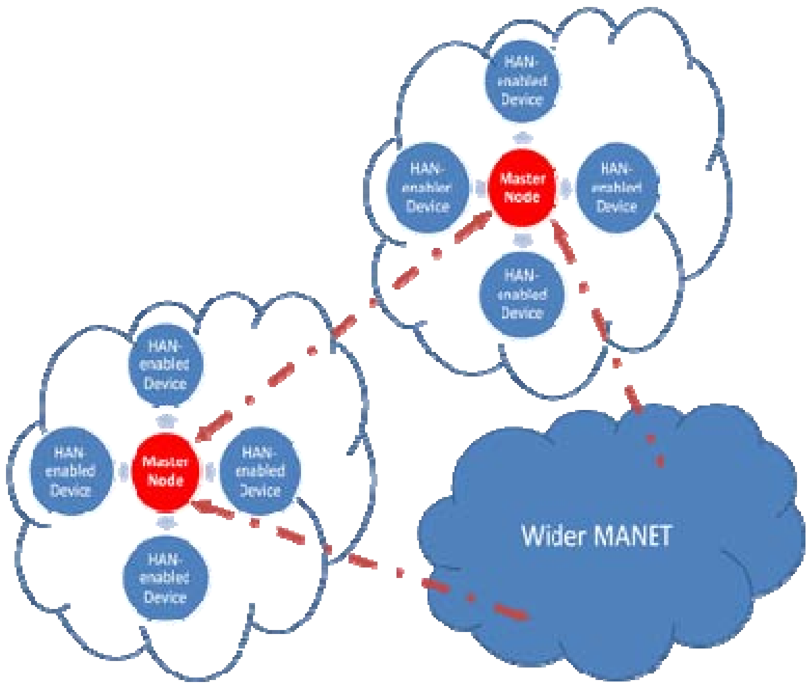

Figure 36. NbT Network Topology

Assume that HAN master devices (a) have the intelligence to sense not only the presence of other HAN-enabled nodes, but also multiple wireless networks, (b) are provided with the local characteristics of individual wireless networks that can be used in deciding which network to switch to, and (c) have the hardware to switch among multiple networks.

In this “smart” network, HAN/IBC-enabled nodes have the capability to sense, to reason and to be aware of the content knowledge and behavior of users and the environment. The network automatically provides active services to users according to their situation. HAN-enabled devices (i.e., smart terminals) are the end-system components that can communicate with the smart network through touch, and access the network services and context-aware information. Of course, HAN functionality and services take place only for the discrete time and space that HAN-enabled devices are establishing connections and interact to exchange data. This defines specific scalability limits for physical touch. Furthermore, associated services and subtasks continue to span the entire MANET or other backbone networks and the Internet. These services are which are expandable in time and space even after the touch connection is terminated. These services are immediately available when a simple touch connection is established again.

In order for the information to be disseminated, assume a logical layering structure is built as shown in Figure 37.

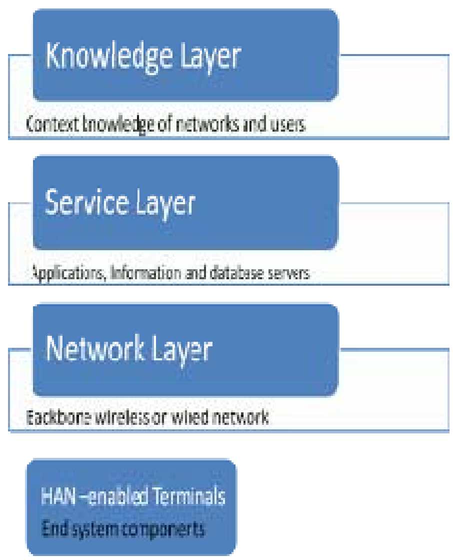

Figure 37. Logical Layers of a "Smart" Network Framework

In this diagram, the network layer is the underlying network consisted of interconnected backbone networks and wired or wireless access networks. It establishes links, provides routing and switching capabilities for data packet transport from end-to-end. The service layer provides application services through several dispersed database servers or the internet. The knowledge layer on top of the service layer contains the content knowledge of the networks and users.

B. TOUCH INPUT/OUTPUT AND INTERFACE WITH WIRELESS AD HOC MOBILE NETWORKS

1. Touch Network Functionality

As previously described, HAN functionality and services take place for only a discrete time as transparent, intuitive functions to establish an information networking connection between HAN-enabled devices. What are the component functions within this exchange? This thesis assumes a layered model as depicted in Figure 38. It is similar to the TCP model with the exception of introducing a bundle forwarder that utilizes DTN capability between the transport and application layers.

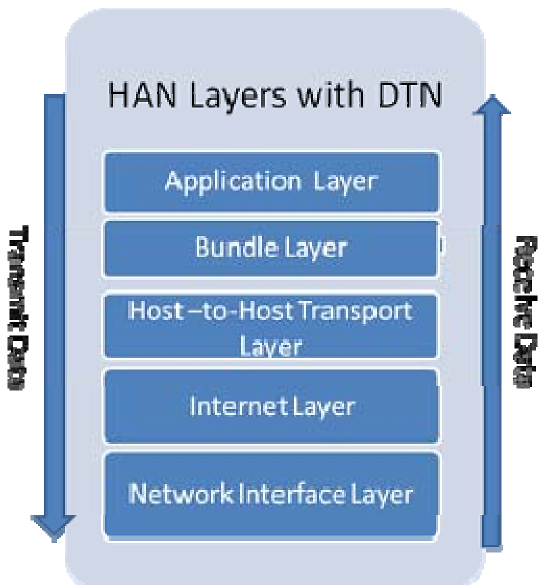

Figure 38. Touch Networking Model

The *Network* Interface layer is the lower level layer that constitutes the physical link, which delivers data through the human body and/or HAN-enabled devices. The *Internet* layer is the networking level that fragments packets and manages addressing and delivery of packets between hosts utilizing the networks. The *Transport* layer manages the transfer of data by using connection oriented (TCP) and connectionless (UDP) transport protocols and manages the connections between networked applications. The *Application* layer refers to standard network services and communication methods used by various application programs, where it defines compatible representation of all data. The most significant layer in this structure is the *Bundle* layer that operates between the Transport and Application layers. It provides the capability to access network contents based on descriptions of content rather than specification of the end node at which it is located. It receives or processes bundles that internally group metadata and data, even if connectivity is disrupted. When connections are restored, the network and application layers are again active for a small fraction of time providing services since the nodes retain opportunistic copies of content.

2. HAN Connection Protocol

This TCP-based protocol provides the service of reliably exchanging data directly between two NbT nodes. Over time, the networking connection undergoes a series of state changes schematically shown in Figure 39.

Initially, nodes are waiting for a connection request from any remote client. This happens only when the nodes sense human contact or the proximity of another HAN-enabled device. One of the two nodes serving as the master periodically announces its presence. The other nodes should continuously listen for synchronization announcements in order to achieve connections. Indeed, when touch is applied, a connection is established in a diminutive time frame. Next, the master, or source device, alerts automated applications, which utilize the network so that they can resume activity and pass application data. The connection terminates at the moment the user stops contact with the other device. Although the physical link is terminated, the communication link temporarily remains until the TCP connections providing automated services over the network time out. Even after the TCP disconnection, applications designed to function over this network do not necessarily degrade fully: they may stay in a suspended mode and could re-initiate instantly if a new connection occurs because of DTN’s caching and opportunistic storage of data.

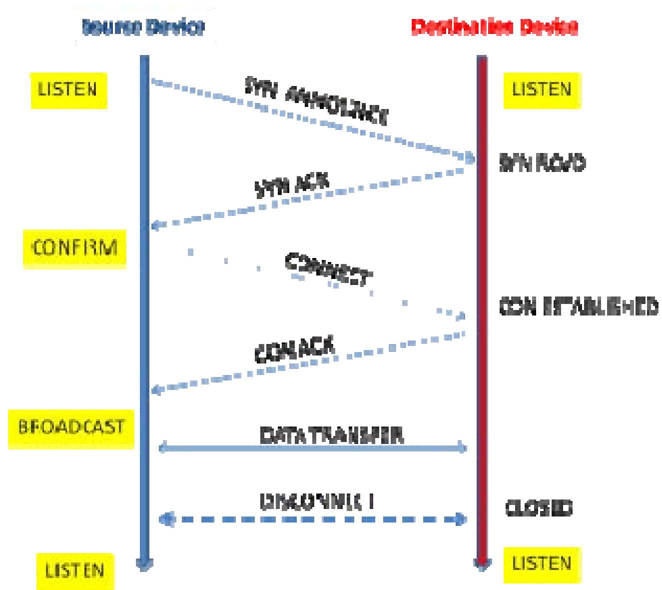

Figure 39. State Changes of a Dynamic Touch Connection

3. Touch Network Interface With MANETs

A standalone touch network may not provide the networking resources necessary to allow highly reliable communications. Access to and switching among multiple networks may create a fault-tolerant architecture. A reliable wireless network reach-back architecture allows small units, that exchange touch or tactile inputs/outputs, to receive only necessary signals, thereby, decreasing the physical load and at the same time accessing multiple ad hoc networks, while expanding the range of reception and available resources to the limits of the entire network. Another benefit is the ability to overcome time and/or location-sensitive connectivity problems and failures in one network by switching to another. The incorporation of data aggregation is also beneficial: it provides data redundancy and the ability to compensate for node failures. In this case, one node plays the role of the “aggregator” node within the cluster, thus enabling aggregation of the data to be performed locally, reducing the communication bandwidth requirements and limiting the network response time. Another beneficial possibility for this networking framework is the application of the DTN technique to all nodes and clusters: exploitation of soldier-captured information can be passed quickly and correctly back to the higher echelon commands through NbT interfaces that use DTN protocols to mitigate intermittent connectivity via the wider network clusters. Alternatively, DTN architecture may forward key data and knowledge to weary small unit leaders through touch interfaces. The advantage of that is once end-to-end connectivity between HAN-enabled components is established in discrete time and space, it remains continuous for that session and exploits available network resources independent of the overall network condition, due to the opportunistic data caching and storage of DTN technology.

4. Operational Advantages of HAN Services

When HAN-enabled devices interact, they have the ability to perform invisible intuitive functions providing services to the user/soldier that automatically reconfigure depending on the mission characteristics and requirements. A soldier can deliberately empower HAN-enabled devices (e.g., a hand-held radio) to execute certain scripted actions (e.g., to automatically download and program frequency hopping sequences and tactical radio network keys from his personal device) when the user alerts these devices through the power of touch (e.g., picking-up a handset) [29]. If another platoon's soldiers are executing a different mission, the automatic reconfiguration capability applies the same action: it automatically tailors the radio sets to meet its own communications requirements.

In real operations involving close combat situations, little time is available for deliberate planning and generating options. Soldiers, especially in the high tempo parts of plan execution, need rapid ways to deal with dynamically emerging situations. In particular, they might need to review plans, to resynchronize their operations with adjacent friendly forces, or to get alerts for unanticipated threats. In fact, at the squad/platoon level, the soldiers could carry already developed portable or wearable interfaces as planning and decision aids.

DARPA developed a soldier-borne system running as a Java applet[12] [81]. This "glance and select"-style interface requires very limited modalities of input and output. Consider the enhanced capabilities that the NbT notion provides to the soldier. For example, the synchronization matrix and execution checklist displays in the soldier's decision aids interface would contain not only specified tasks, but also suggested implied tasks pertaining to the current mission environment and past data retrieved for the individual by his/her wearable NbT device. Certain benefits for the decision support process and shared SA are also obtained from this implementation including:

a. The automation of the decision-making processes in a manner that is transparent to the soldier. Indeed, the soldier's HAN-enabled device presents him/her a consolidated, relevant, clean list of courses of action obtained from filtered and fused data, thereby avoiding the redundant information circulated into the planning system. Since the soldier's data has been initially extracted and entered into the planning process through touch (HAN/IBC), the proposed output is tailored to his mission model and presented to him/her in the right format and at the right time.

b. The dynamic upload of the soldier's mission profile from his HAN-enabled device into the intelligence system's database, which is continuously updated.

In time-critical situations where there is insufficient time for a human operator to respond and take appropriate action, high-level automation of the decision and response management are justified. This thesis operates from the belief that this is the case for the NbT and generally the HAN-oriented technologies. Table 2 presents Sheridan's System of eight Levels of Authority,

[12] A number of related projects developed by DARPA, seek to support small military units using interfaces that provide map-based overlays or sketches, a temporal "synchronization matrix" and "execution checklist" displays. The most recent includes a multiple-resolution map display on which time-phased positions of friendly and opposing forces can be shown, along with synchronization points and times in relation to adjacent friendly forces, and an execution checklist. [81].

which indicates the amount of automation incorporated in the response, its level of autonomy and whether the response execution authority is assigned to the system or to the operator [82]. Sheridan's levels vary from *level 1* – "computer offers no assistance, human does all" to *level 8*—"computer selects method, executes task and ignores human." In levels 1 through 4, the operator has authority over function execution. In levels 6 through 8, authority is moved to the system. This thesis assumes that NbT and HAN-oriented technologies provide equilibrium between human and computer interaction and better harmonize with *level 5* of the table where the authority is shared between the system and the operator.

Level	***Computer Task***	***Human Task***
1	No assistance	Does all
2	Suggests alternatives	Chooses
3	Selects way to do task	Schedule response
4	Selects and executes	Must approve
5	Executes unless vetoed	Has limited veto time
6	Executes immediately	Informed upon execution
7	Executes immediately	Informed if asks
8	Executes immediately	Ignored by computer

Table 2. Sheridan Levels of Authority (From [82])

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IV. ANALYSIS FOR OPERATIONAL IMPLEMENTATION PLAN

The establishment of the conceptual model in the previous Chapter is the first step towards implementation of NbT technologies. Another step is to acquire more comprehensive findings through experiment involvement in order to explore venues for the military sector to benefit. Having developed the tactical NbT concept and a proposed framework for its function, this thesis proposes a reasonable extension of these to a field research effort. This Chapter assesses the adaptation of these technologies their feasibility and implementation challenges in TNT MIO-oriented field experiments.

A. FRAMEWORK FOR EXPERIMENTATION

NPS's Center for Network Experimentation and Innovation (CENETIX) provides a venue to evaluate HAN-enabled technologies and conduct hands-on assessments of HAN-enabled devices. According to the NPS's command brief [83], CENETIX "provides interdisciplinary studies of multiplatform sensor-unmanned vehicle-decision maker self-organizing networks; tactical network integration with Global Information Grid, collaborative technologies, various forms of multiplatform wireless networking, Situational Awareness systems, and multi-agent architectures. It also integrates and operates NPS-SOCOM Tactical Network Topology (TNT) and Maritime Interdiction Operations (MIO) testbed." Under the sponsorship of CENETIX, the TNT testbed acts as an applied research channel of social and information networking, which encompasses prospective commercial-off-the-shelf (COTS), and government-off-the-shelf (GOTS) technologies and tools in order to make them available for operational use. Indeed, the testbed's service architecture is an interface system for field experimentation. The TNT MIO testbed includes a plug-and-play wide area adaptive network (see Figure 40) with global reach-back capabilities and rapidly deployable self-forming wireless clusters that provide the basis for quarterly TNT MIO-oriented experiments. The net-centric tactical and C2 experiments primarily serve the Collaborative and Knowledge Management (CKM) requirements of United States Special Operations Command, other Agencies of the Department of Defense and the Department of Homeland Security, and Coalition partners. This unique experimentation environment allows testing of proof of concepts for collaborative technologies in tactical scenarios, as well as evaluation with operational metrics.

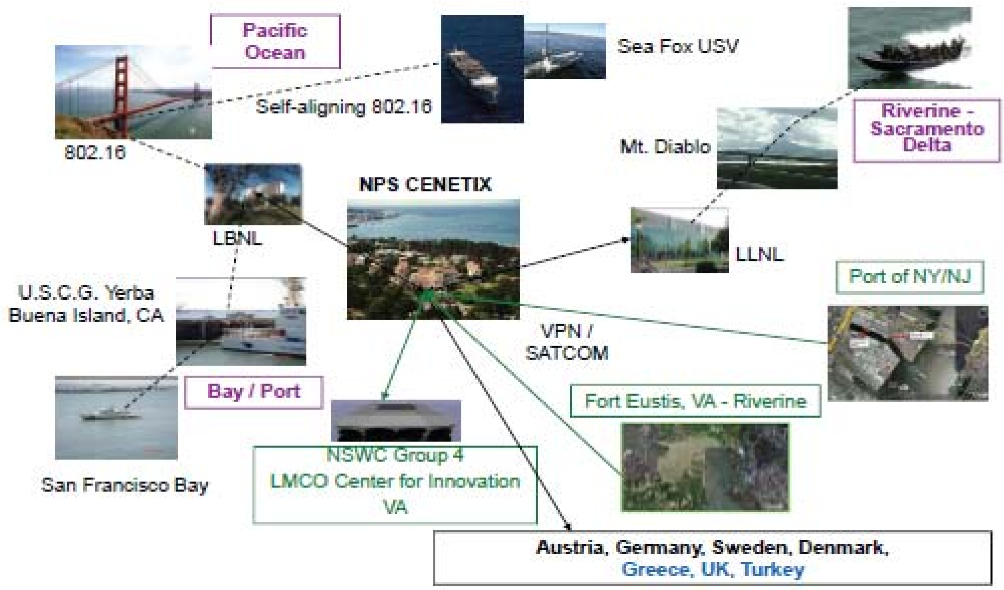

Figure 40. Plug and play TNT MIO Testbed Segment: SF Bay, East Coast and Overseas (From [84])

The Tactical Network Topology (TNT) for Maritime Interdiction Operations (MIO) is comprised of a backbone 802.16 OFDM wireless network link with stationary and mobile Network Operation Centers (NOC) for C2 and data capture. Into this architecture are integrated various rapidly deployable self-forming wireless clusters of land, air, and sea, manned and unmanned components using ITT/Wave Relay Mesh, Broadband Wireless Mesh/Point-to-Point, self-aligned 802.16, UWB, MIMO N-LOS, GSM/GPRS and SATCOM. Extensions to this topology constitute various local networking clusters for sensor mesh mobile networks based on ship-to-shore, ship-to-ship, ship-UAV-ship, ship-USV-ship and ship-to-UAV communications, depending on the executed experiment scenarios. Robust software technology tools like the Groove Virtual Office for collaboration and data sharing[13] and the Situational Awareness Agent for near real-time data projection (positional icons, alerts and messages) are available through VPN tunneling between all nodes and remote collaborators.

B. ADAPTATION OF NbT TO TNT MIO EXERCISE SCENARIOS

The following is a brief description of aspects of the operational scenarios usually executed in TNT MIO exercises:

a. TNT operational scenarios investigate various topics related to tactical networking with sensors and unmanned aerial systems (UAS) and collaboration between dispersed units focused on high value target (HVT) tracking and surveillance missions.

b. MIO scenarios focus on interdicting the smuggling of nuclear radiation threats, contraband cargo (e.g., weapons and narcotics) or terrorists. Tactical wireless networks support vital near-real time feedback between tactical operators and C2 organizations. This feedback enhances SA and decision-making. The networks also enable remote experts to exchange near-real time information in the areas of radiological threats, biometrics, and response activities.

Opportunities for initial adaptation and evaluation of aspects of this technology come into view in the MIO scenarios primarily in the support of tactical Boarding Parties (i.e., similar to an army squad) that seek to interdict those smuggling activities in maritime environments. The envisioned network diagram in Figure 41 presents the interdiction and data sharing process between a Boarding Party (using HAN-enabled devices and peripherals and wearable tactile displays) and the collaborative networking environment that supports experts C2 feedback and expert reach back.

[13] The Groove Virtual Office is a software collaboration tool that provides shared workspaces, real-time text chat, voice over IP, streaming video, etc.).

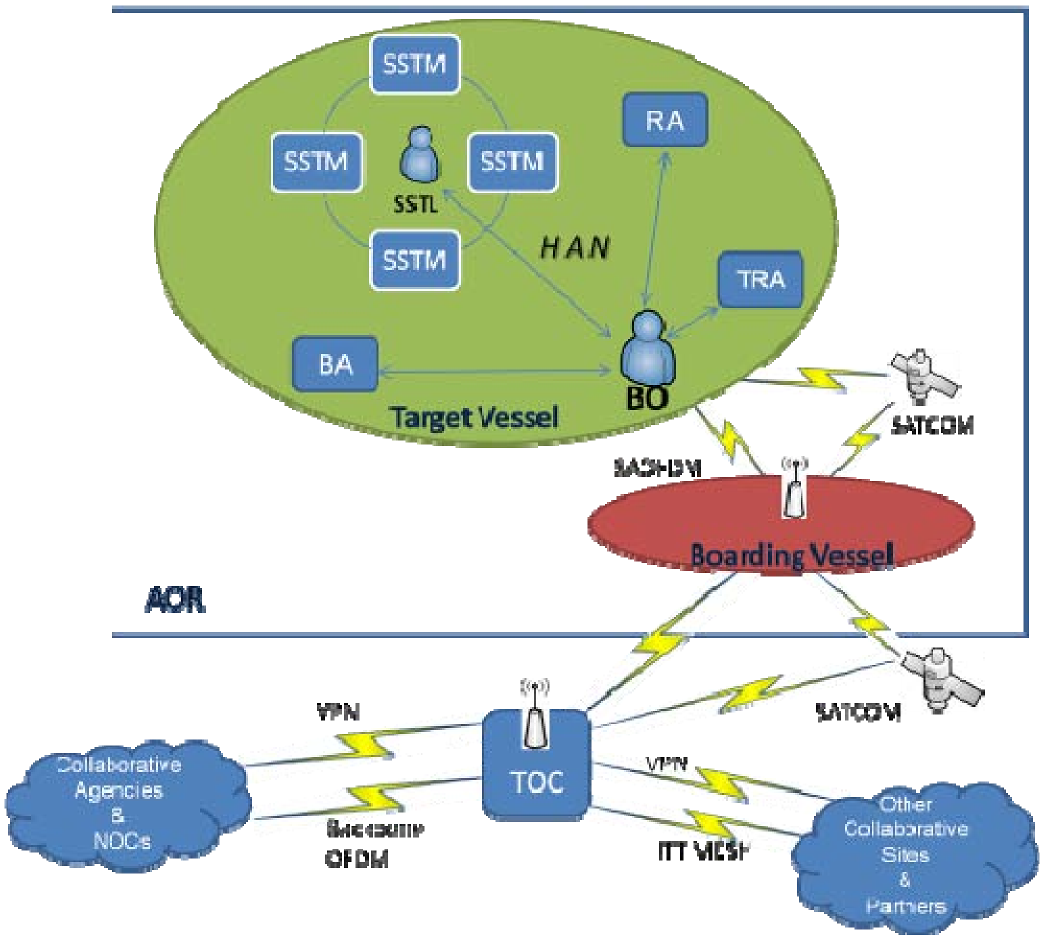

Figure 41. Interdiction and data sharing between a Boarding Party (using HAN-enabled devices and peripherals and wearable tactile displays) and the collaborative networking environment with experts' reach back.

The following scenario represents a possible way to integrate and explore NbT technologies in a TNT MIO event:

After various stages of MIO operations (i.e., stand-off detection, tagging, and tracking) a small craft believed to be smuggling some contraband must be stopped, boarded and searched. It is the task of a Boarding Party to gain access to the craft and search it for suspicious material. At this point, the efficacy and benefits of using HAN-enabled devices and peripherals can be explored. During this phase, the Boarding Party not only conducts a detailed search of the craft, it also supports MIO connectivity and collaboration necessary to support both C2 SA at various operational levels, and radiation awareness, biometric identification, non-proliferation machinery parts identification, and explosive materials detection [86]. The Boarding Party members consist of a Boarding Officer (BO), a Safety and Security Team Leader (SSTL), SST Members (SSTM), a Radiation Agent (RA), a Biometrics Agent (BA) and a Threat Reduction Agent (TRA). Each can be equipped with HAN-enabled electronic devices such as laptops, PDAs, cameras, sensors and readers.

Upon arrival and boarding the target vessel, the SST searches the target ship while the Boarding Officer establishes wireless communications with the Tactical Operation Center (TOC) and VPN access to the TNT MIO collaborative tools. Through those communications links, information can be uploaded, and feedback and reach back information can be obtained to assist the BO in accomplishing his/her mission. The SST is also equipped with wearable tactile displays that allow for a local communication network between the team members to exchange basic tactile language cues and provide directional warning and attention allocation to the direction of potential threats. This is potentially beneficial since the SST typically operates under conditions of poor visibility throughout its search operations in the relatively confined spaces of watercraft. The sense of touch with realistic feedback from the haptic devices is likely more important than the sense of sight in order to focus on the environment and possible threats.

Another practical implementation of haptic devices is the hazardous “tagging” part of the operational scenario performed by divers. Divers can be aided in their efforts by receiving data from various sensors, and a near-real time display of mission information using tactor technology for steering indicators in extreme underwater navigation conditions such as those described in Chapter II/ Section E / Subsection 1 / Sub-subsection b.

While the vessel search is being performed, thorough inspections and data collection processes are conducted by the RA, BA and TRA elements. During this data collection phase, the biometric data measurements obtained from crew (e.g., digital fingerprints, iris recognition data, etc.) and the radiation/explosives signatures acquired with the help of HAN-enabled peripherals are automatically transferred and stored to the respective Boarding Party member's "smart" device through a simple "touch" operation. Additional data, such as video and still imagery, can also move in a similar fashion among the Boarding Team. Then, team elements transfer all relevant gathered information connecting instantly their devices to the BO's HAN-enabled device using the same method of touch-activated interfaces. The end user (i.e., the BO), by placing his/her smart device on a target point on the BO laptop computer or other mobile terminal, can send (i.e., upload) the gathered data and make it available to the C2 workspace. After timely collaboration with and analysis of the data by the remotely located experts and respective operational commands, turn-around results are available to the BO within the boarding allotted time.

C. IMPLEMENTATION OPERATIONAL ADVANTAGES

The option of even incremental integration of tactile and/or touch technology into future MIO experiments presents enhancements to the usual methods of collecting, processing, and disseminating time-sensitive data.

At first, there is the significant ability of touch networking to quickly assess situations, collaborate with responders and interpret incoming data. The Boarding Party using touch interfaces avoids time-consuming procedures for downloads and data transfers as it stores all relevant information for correlation with later feedback information that is now easier to pull up at any time.

Secondly, the wearable tactile displays (e.g., vests or belts) of the SST provide spatial orientation to the team members, and the ability to detect and determine the relative position and motion of targets and each other. The HAN-enabled devices worn on the human body contain information relative to the user's task knowledge and the environment, and empower him/her to deliberately interact in an intuitive manner to any of the surrounding HAN-enabled computer appliances; in this case humans that carry or wear similar equipment. To achieve this interconnection these devices use touch or IBC interfaces.

Another possibility, as previous research suggested [29], is to embody all the electronic real time capturing equipment, like IED detection devices earpiece-microphone sets or digital camcorders, on the same wearable device networked with the TL, the TOC and rest of the collaborators, in order to expedite their work in a "hands-free" manner.

Then, we infer that team collaboration is more effective and its decision-making capability is enhanced in this dynamic and complex data flow. The time pressure and the uncertain conditions replete in MIO operations are critical parameters that denote the benefits of using such technologies.

Lastly, the wearable smart devices of a Boarding Party's element (i.e., human nodes) automatically provide GPS feeds or other near real-time data (e.g., audio, images, video or human inputs) over the collaborative network to the shared SA view. This enhances the net-centric view of the Area of Operations.

D. EVALUATION OF NbT IN MIO EXPERIMENTS

Data transmission by touch and HAN-enabled technologies may be evaluated within the MIO experiment domain as part of the self-forming mesh networks supporting highly mobile human operators. During the execution of an MIO experiment, there is a great opportunity to use the existing suite of network monitoring tools of the TNT testbed to evaluate network Measures of Performance (MOP) regarding the implementation of touch or tactile technologies. Network performance metrics obtained for HAN-enabled marketed "smart" devices like the TransferJet ™ (described in Chapter II / Section E / Subsection 7) operating either as stand-alone devices performing locally or networked as last tactical yard components of a reach-back network can be compared to the existing network performance metrics. Positive results are a fundamental step towards determining the efficacy of these concepts and technology. Some relevant MOPs for evaluating NbT technologies and concepts include:

a. The time needed for establishing connections and the data rates associated with exchanging information between peripheral and HAN-enabled devices.

b. The relevant time for uploading information and acknowledging an understanding of that shared information.

c. The data processing limits of the devices and the acknowledgement of a saturation point where receiving more input leads to improper functionality due to overload of information.

d. The possibility of latency of concurrency and the developing of backlogs.

Most of the technical aspects and the shortcomings of the tactile technology can be evaluated to reduce uncertainty regarding meeting operational requirements of the missions examined.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY OF CONCLUSIONS

This thesis addresses the implementation of physical or electronic touch for data transmission via highly adaptive human area networks. It infers the feasibility of NbT technology to support a range of military operations for small units requiring mobility and a highly adaptive ad hoc organization.

In Chapter II is a presentation of the technology's background material, its fundamental operating principles, and an overview of applications of Networking-by-Touch. In Chapter III, the feasibility of a common network architecture for small units is proffered to integrate HAN/IBC technologies into those networks. Finally, Chapter IV proposes an operational implementation framework based on TNT's experiment opportunities.

In laboratory conditions and in some marketed applications, data transmission by touch has proven its functionality as a transparent, intuitive and rapid information exchange technology between HAN-enabled devices and peripherals. Nevertheless, it is still not validated in military networking environments, either as a standalone last tactical yard mesh networking configuration nor as an integral part of existing network paradigms. Furthermore, architecture and standards for HAN-enabled technologies or terminals do not exist presently, but as depicted in Chapter III, they are feasible. This condition sets operational constraints on integrating "transmission-by-touch" into mobile tactical networks and is holding up a mature HAN implementation. Even if the above is true for large echelons, there is great potential for the evaluation of HAN/IBC-enabled devices in small-unit networks. The social networking capabilities that apply to small units provide a solid platform for bringing HAN/IBC technology to fruition. The networking size of a platoon or squad corresponds well with the specific scalability limits for physical touch. Social Networks dynamics shift the social networking services from centralized Web based to delay-tolerant distributed storage for disconnected MANETs.

One aspect of haptic technology is the tactile displays, specifically the Tactile Situational Awareness System (TSAS) that makes up a mature approach to augment the receipt of intelligent communications and aid soldier performance in a hostile environment. To explore that, extending this technology to ad hoc mesh networks between human nodes wearing collaboration communication capable vests would be beneficial, such as in a squad/platoon cluster where dynamic node entries, departures, and exchanges of critical information frequently occur in missions conducted in complex operational environments. The human nodes when in relative proximity can quickly exchange directional or vicinity warnings, threat composition and disposition, SA updates or navigation information under low visibility or high noise conditions. Moreover, the ability to rapidly expand a collaborative environment until the last mile/yard is essential to the timely response of civil and natural disasters—hence, this technology does not apply only to military operations.

HAN/IBC–enabled nodes constitute the important structural components and HAN/IBC-enabled devices constitute the necessary end-system components of a “smart network” that is adaptive and self-forming, capable to sense, to reason, and to be aware of the content knowledge and behavior of users and the environment. This network automatically provides services according to the user’s situation and operational requirements.

Another conclusion pertaining to the advantages of HAN-enabled technology is the automation and transparency of the decision-making process. The interaction of wearable and/or standalone devices that filter and fuse data and eventually presents to the soldier a consolidated, relevant output—in the right format and at the right time—that is tailored to the mission. That improves speed of command and mission effectiveness, and subsequently the accomplishment of the operational objectives.

In this research, a beneficial factor for seamless function of NbT applications in ad hoc “touch” networks performing as clusters under the wider tactical wireless networking environment is identified—i.e., the fit of DTN techniques into the system architecture to mitigate intermittent connectivity. The advantage of NbT applications is that once end-to-end connectivity between HAN-enabled components is established in discrete time and space, it remains continuous for that session and exploits available network resources, independent of overall network disruptions. The potential for this networking framework to provide services, even under temporary disconnections, due to jamming, for example, is tremendous. Due to DTN’s inherent opportunistic caching and data storage, soldier-captured information transfers through NbT interfaces in small-unit network clusters and is available via the wider backbone network to higher C2 echelons. Alternatively, the DTN architecture facilitates the forwarding of processed and disseminated key data and knowledge to the last yard small unit leaders through touch interfaces, irrespective of weary conditions.

This thesis concludes that NbT functionality is a technological enabler towards the ultimate objective of Network Centric Warfare (NCW), as it provides all elements of the GIG, to include even very small echelons, increased connectivity and access to high quality information.

B. RECOMMENDATIONS FOR FUTURE WORK

1. Integration of HAN-Enabled Technologies (HBN, NFC, IBC) Into Existing Networks

Since complete standards for software and hardware components are not clearly set by the international community, incorporation of HAN technologies or terminals into existing networks is somewhat far from mature. Yet, it does not have to be a completely new network of HAN-enabled functionality at the beginning: Two or three HAN-enabled devices and/or peripherals functioning in a wider LAN would suffice for monitoring basic performance metrics for testing and evaluation. The NPS field experimentation program with the aid of NPS’s TNT testbed provides an excellent venue to evaluate some of the currently marketed products and trends. This venue provides some excellent opportunities to address some of the considerations and drawbacks of each technology, such the limited bandwidth or security issues. The next step is to enhance the existing networks with more dynamically capable elements as technology matures.

2. Sensor Networks

Another field that may benefit from the implementation of the proposed NbT technology is the interaction of human operators with Sensor Networks (SN). The network-centric structure of SN typically accommodates robotic platforms to collect information through observations with on-board sensors and a plethora of automated applications that enable reach back. A current limitation lies with the incorporation of the information perceived by human operators through their senses into the SN. The concept that needs further exploration is the use of integrated HAN-enabled technologies by the human nodes to locally perform data fusion, and then transfer critical information to the decision-making network components. A wide research lane exists towards this integration challenge and the smooth incorporation of additional information perceived by humans into the last mile mesh networking tactical environment.

3. HAN System Architecture and Interfaces

To realize a sustainable architecture for “touch” networks, a suitable interface to the reach back network is needed. From the software point of view, it is necessary to establish unobstructed access to multiple networks and expand the range of reception and available resources to the limits of the entire network. A platform to achieve this seems to be a design framework for dynamic networked systems of software and hardware components, such as the Service Oriented Architecture (SOA) for instance [29]. Further research regarding this aspect of the unification of different platforms is intriguing, but keeping their inherent characteristics and self-dependence is vital.

4. Tactical Situational Awareness System

The TSAS, with its variations, is a tangible starting post for future experimentation to meet the operational requirements for small-unit ground troops. There is a lot of space for research in developing sustainable ad hoc mesh networks based on wearable tactile displays that support dismounted soldiers focused on possible threats; these include (1) divers in dark waters, (2) fire fighters experiencing low visibility conditions, or (3) SOF squads in covert operations. The networking research aim is to enhance the capability of exchanging more complex, context-specific data between operators.

5. DTN Perspective

DTN promotes cognitive, adaptive wireless networking and is a solid step in the process to develop content-based networks. Prior analysis in this thesis identified advantages of shifting the tactical network management towards a "Network-on-Target" approach [85], a high-speed edge (described in Chapter II section C subsection 4) rich in internal connectivity and bandwidth resources. Further research is required in this area to enable HANs to carry out aspects of this type of organization of the information in networks self-contained and self-reliant networks with considerable inherent capability.

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APPENDIX. BASIC CODING SCHEMES AND COMMUNICATION PROCEDURES FOR NETWORKING WITH TACTILE DISPLAYS

The Tactile Situational Awareness System for Ground Forces (TSAS-G) is an evolving application of wearable tactile displays that augment the receipt of intelligent communications and aid soldier performance in a hostile environment, and under low-visibility or high-noise conditions. In most instances, low echelons (e.g., squads) take advantage of such innovations (e.g., tactile vests or belts) that are capable of conveying basic commands and short “bits” of information to the soldier rapidly and without additionally burdening the eyes and ears. Recent studies of land applications including directional threat warning, dismounted soldier navigation, and communicating arm and hand signals [56] reported the potential of simple tactile displays with no more than eight tactors attached to a belt around the waist of a soldier (see Figure 42).

Experimental work to date [61], [62], has adopted the tactile analogy of a sampling of remotely communicating U.S. Army arm and hand signals that soldiers are well versed in, such as those depicted in the first column of Table 3. These studies, directed by ARL with the support of UCF, evaluated infantry soldiers’ abilities to interpret and respond to tactile commands while completing a combat patrol simulation obstacle course.

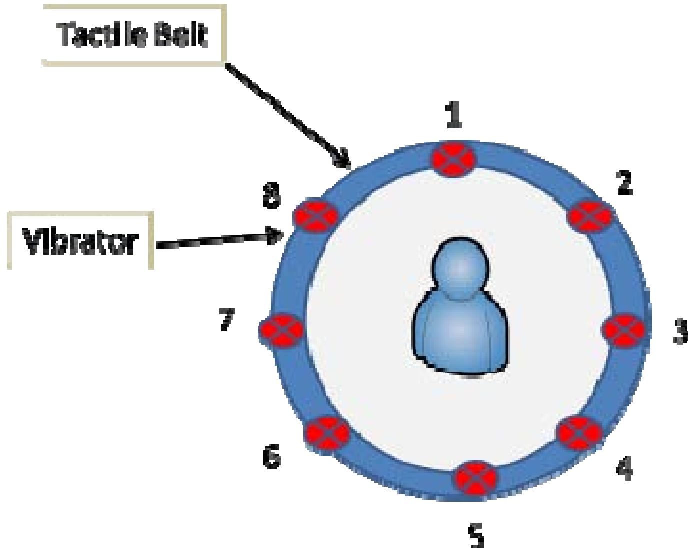

Figure 42. Simplistic design for a tactile belt and associated tactors topology (After [58])

The following table is a summary of experimentation results obtained from notable research efforts in this area, and presents a basic coding scheme for networking with tactile belts, suggesting correspondence of major visual hand and arm signals to tactile actuations.

Visual Signal	Hand Signal Equivalent	Tactile Signal Equivalent	Tactors Activated
ATTENTION	Arm extends forward just above the head with the palm facing forward and is signaled with a hand-arm waving motion	Sequenced side-to-side activation of front tactors, creating a "wave-like" motion.	First left to right #8-1-2, then alternates from right to left #2-1-8 repeating iterations
HALT / STOP	Hand is raised with palm forward.	Simultaneous surround activation of all tactors.	# 1 through 8
MOVE OUT	At first, facing to the direction of movement with the arm held overhead and behind. Then swinging the arm forward to the horizontal and pointing	Sequenced back-to-front activation of tactors, creating movement around each side of the body, to converge in the front[14].	#5 first, followed by #4-3- 2-1 and #6- 7-8-1 simultaneous sequences. Then activation only of #1.

[14] Visual direction is implied by the way the body is facing in the "move out" command. Tactile direction is signaled only after the "tactile move out" command, by activating the tactor that signifies the direction of the movement.

	toward the direction of movement.		
RALLY	Raised arm, circling overhead	A traveling pulse around the body clockwise, for a number of iterations, creating a circular motion	#1-2-3-4-5-6-7-8 continuous iterations
NBC	Extending both arms to horizontal and then quickly bending the arms toward the shoulders repeatedly (as donning protective gear)	Pulsing of the two side tactors simultaneously for a number of iterations (as an intuitive emulation of tapping the shoulders with the fingertips).	#3 and 7

Table 3. The five key signals, and their suggested correspondence to visual hand and arm signals (After [56],[61],[62])

Another more sophisticated transducer-based design recently patented [25] uses electromagnetic field sensors combined with electromagnetic transducers as input devices (see Figure 9). The transducers deliver vibration into the skin via a moving contactor. Conversely, when the contactor is physically moved with one's finger (e.g., a tap), the device generates a change in the electromagnetic field captured by the sensors. Using multiple tap patterns among multiple transducers allows for flexibility in the number and types of commands sent via the display [25]. Consider a remotely located leader that uses a control interface (e.g., a PDA or a pocket personal computer) with a touch screen in order to communicate to the soldiers wearing this belt array. The control can send and receive signals to and from the tactile belts via wireless protocol 802.11, Bluetooth, RF, IR, etc., to a driver hardwired to the belt. With this wireless tactile system, when the TL has a message to pass, the TL activates a control interface with a touch and communicates information to the wearer. Conversely, the soldier can acknowledge commands or tap out coded messages similar to the Morse code by stimulating his/her belt's electromagnetic transducers in a predefined sequence. In addition, the TL can monitor the team's physical well-being at all times through the detection of change in the pattern of EMF signals transmitted from appropriate sensors placed on soldier and received by the hardwired driver on his/her belt.

Based on a similar design, a practical military scenario described in [25] involves an SOF team. When a target pops up to the left of the soldier, the wearable computer can detect a sound and/or visual emission and immediately send a signal to the electromagnetic transducer on the belt (per se tactors #7 or # 8 in Figure 42), and a consistent vibration can begin near the left hip. As the soldier pans left to the target, the vibration can move right across the waist of the soldier. When the vibration becomes centered (at tactor #1), over the belly button of the soldier, that is the cue for the soldier to aim his/her weapon and fire.

In other words, it is feasible to develop a network of tactile displays with wearable computer sensors, communicating basic information, based on monitoring the EMF status of the displays and responding accordingly to detection of a specific pattern of EMF change.

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