Two-Level ZigBee-4G Design for Secure and Efficient Communications in the Resources Constrained Military Environment

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Summary
The widely acknowledged problem of hostile and dynamic military environment introduces several new challenges for efficient and secure communications of coalition armies. Mobile Ad-hoc Network has been the subject of much research recently as a solution due to its dynamic and light weight infrastructure and 4G has been considered as a future of cellular communication systems to the commercial world for the past decade. In this paper, we explore and propose new light weight secure wireless network, "*4G-Zibee*", for future battlefield by combining MANET, 4G and light weight efficient wireless network protocol called Zigbee. We believe this paper also helps researches in this area to set the realistic guidelines by providing current and foreseeable future resource constraints in terms of power, bandwidth and memory.

Key words:
ZigBee, 4G,Military Environment, battlefield communication, MANET

1. Introduction

Recent studies have advanced to a point where MANET (Mobile Ad Hoc Network) implementation becomes reality. In the foreseeable future, networks of mobile devices that can cooperate and effectively communicate without backbone infrastructure will significantly influence and simplify our lives. The possible situations where MANET will play an important role will touch almost every aspect of our lives. People who are much dependent on their technical devices will be able to move to a level where a simple device will allow them to not only communicate with every one, everywhere, but also access information stored in some place miles away from their present location. Transmission of multimedia and ordinary files will find application in disaster situations, battlefields, expeditions, in places where communication infrastructure does not exist, as well as in places where already existing complicated communication infrastructure and its quality can be simplified and raised.

This paper examines MANET primarily from the perspective of military adaptation; however, business and industry perspectives are also included due to their significant influence on the research.

This paper also presents an overview of significant improvements in MANET's development and suggests real data implementations of already collected information in consideration of today's physical limitations. Although much research has been done that focuses on introducing and supporting new techniques that can increase performance and solve various issues concerning MANET, besides computer simulation, no real-life work has been done to physically prove the strength of these arguments and investigate whether future work to keep improving upon some solutions is still necessary to produce an acceptable device for MANET. Very often simulation does not correctly provide meaningful information about physical constraints that were assumed during testing, like bandwidth capacity, speed of nodes, etc. Moving closer towards physical implementation of already presented research, real physical constraints of MANET's devices will play an important role especially during the final stages of research where areas that need more improvement will be made apparent.

Present technology especially in areas of memory, bandwidth, and power, as well as new technological solution that should be available in near future are investigated in this paper. This paper should be able to present a picture of the physical constraints of MANET at present and also suggests some areas where previously considered as limitations may no longer exist, or will vanish in the near future. Hopefully this will allow other researchers to set reasonable constraints and physical boundaries for future research, tests, and simulations in

Manuscript received October 2, 2007
Manuscript revised October 20, 2007

MANETs.

This paper is organized in the following way: Section 1 introduces this paper. Section 2 presents brief background of MANET and their impact on our proposed research. Problems concerning the real-time, i.e., actual data application of MANET are presented in Section 3. Section 4 and its subsections illustrate realistic MANET constraints in terms of power, memory, and bandwidth. Section 5 introduces the two-level ZigBee-4G design, which focuses on conservation of electrical power in the military environment. The symmetric key security for the wireless communication of the proposed ZigBee-4G design is evaluated in a military scenario presented in Section 6. Finally, Section 7 concludes this paper and also discusses future work of actual data constraints in the implementation of MANET based on current research.

2. Overview of the MANET Research

Around the world, researchers are working to implement MANET for business, organizational, and military purposes. Quite a number of important and interesting solutions have been presented to date. For example, already offered as solutions are routing protocols [36, 37, 38, and 39] that significantly increase routing capabilities as well as clarify the possibility of using different routing techniques, given particular MANET situations. Importantly, the real-life implementation of AODV (Ad Hoc On-Demand Distance Vector) and DSDV (Destination-Sequence Distance Vector) [39], and the solution to link and path availability estimation in a mobile environment [37], and comparison between AODS, WRP (Wireless Routing Protocol), DV (Distance Vector), and DSR (Dynamic Source Routing) on the GloMoSim simulator provide significant information on protocol efficiency in different scenarios of node mobility and density. In particular, the A^4LP (Location Aware and Power Aware) protocol [38] includes many aspects significant to the military MANET environment: heterogeneity of nodes and asymmetry of wireless connection with power and location considerations. Another significant for MANET protocol is HWMP (Hybrid Wireless Mesh Protocol) that proposed by Wi-Mesh Alliance as default routing protocol for 802.11s mesh networking standard offers on demand radio metric AODV (RM-AODV) and pro-active three based DV with QoS, load balancing, and power-aware capabilities [31].

Presenting scenario sketches for the military MANET environment, Wolthusen [7] points out very significant, yet often overlooked aspects of different situations where nodes communicating between each other on the battlefield may require non-standard communication techniques and solutions. The diverse routing technologies suggested by researchers looking for a universal solution for MANET, might in fact be combined into a single routing package that, depending upon the scenario, will offer the most efficient communication technique.

Developing upon ideas presented by Wolthusen [7], the two battlefield scenarios, namely the urban platoon level and fluid areas of operation would support the proposition of implementing multiple routing techniques. For example, at the urban platoon level, soldiers carrying communication devices have to be able to create a network without any auxiliary routing devices; however, in a situation where vehicles and other forms of transportation become part of MANET, other routing techniques can be used, with the assumption that these forms of transportation are sophisticated and capable enough to carry technical support to facilitate MANET.

The differentiation between various scenarios in terms of power, bandwidth, mobility, etc., can further the understanding of MANET capabilities and facilitate the choice for the most effective implementation solution. Some researchers have already considered heterogeneity of nodes; for example, Wang [38] presents four classes of devices – from almost unconstrained computers and vehicles, through robots, laptops, PDAs, up to limited sensors, taking into consideration the neighbor transmission relation between nodes of such diversity.

Although not precise, MANET's constraints have been well understood and considered by almost all of the research surveyed, as a significant problem to solve; many researchers are already focusing on techniques to solve these issues. Different caching techniques that would allow more efficient data transmission and middleware solutions that should guarantee network coercion are a few such examples that answer bandwidth and power limitations.

Using proxy servers in MANET is an issue in itself – it is not a question of how, but whether it can be done. On the battlefield, particularly in scenarios where Special Forces of a small commando group without any heavy machinery exist indistinguishable on enemy territory, requests for existence of proxies may fail. However, if machines and vehicles that can create some kind of an infrastructure or support for MANET exist, network proxies and caching techniques are available solutions. According to

Friedman's [42], in comparing different proxy techniques, there exists an optimal solution for the number of proxies that will ensure a high probability of proxy detection: the simulation showed that 2.5-5% of nodes that can provide caching service would be the optimal solution. Generally proxy techniques, researched by Lau [43], such as cache-state (link-state based) scheme and reactive (on-demand) scheme, show that proxies can significantly increase QoS (Quality of Service) and reduce network consumption. As Lau et. al. [43] concludes the effectiveness of caching is proportional to bandwidth and power constraints.

Fig. 1 Using Tank as a Proxy

Understanding MANET's application environment, particularly being able to take a snapshot of particular areas by accessing data about existing and available nodes, and all other available resources, clarifies decision and actions whose goal is to increase the effectiveness of the network. The collection and distribution of such data by middleware can significantly increase network longevity by efficient distribution of power resources. To cite an example of such an approach, Mobile Service Overlay [40] supports management and monitoring of networks, where each node can access and modify such data. Another example of middleware supporting context information of all available nodes was presented by Schelfthout [41].

The above examples suggest that real-life implementation of MANET for solving various problems is quite realistic. Using already available resources to implement MANET prototypes may prove or possibly even disprove the offered solutions. Whereas current technical devices can be used to prove theories, the final implementation, using technology that will be available in a few years, can only be simulated at best, while taking into account future technology constraints. Yet, how seriously should we base our conclusions simply on simulations? Can the presented simulations prove the same research solutions as real-life implementation?

3. Challenges of Past MANET Research

Providing scientific and reliable simulations that support arguments will significantly impact MANET research. As Kurkowski [34] discovers, the quality of presented simulations in research for MANET environment is very low. However, simulations do play a more important role than ever in the MANET development society because they make real implementation available that much sooner. The concrete results obtained during simulation will influence the three-dimension product that will give birth to MANET. The authors of [34] also caution for reliable simulation recognizing near implementation date. According to [34], simulation research to be considered credible should be repeatable, unbiased, rigorous, and statistically sound.

When developing MANETs for military purposes, addition physical constraints, for example, the possibility of no access to recharge or exchange batteries, must be considered. This requires a careful observation of industry where many future MANET implementation issues are being tackled and resolved in order to provide products for customer satisfaction. Also, looking at industry helps further the investigation into issues and solutions for the military environment. The recognition of physical constraints is important not only for research reliability, but also for the successful implementation of devices that will be designed for the survival of communications and the keeping alive of MANET on battlefield.

Recognizing the importance of physical constraints, this survey focuses on the simulation-input parameters in MANET surveys, and the quality and confidentiality of the research conducted in this regard [34]. According to [34], 53% of surveyed papers included in presented simulations the testing area's size and the transmission range; however, only 37% considered mobility and traffic send rate. More over, 13% considered random directory mobility and only 5.3% in their simulations, considered group mobility [34]. In addition, the present survey's review of approximately 50 papers that have included simulation in their research supports the statistics from the authors of [34].

If only 5.3% [34] simulations included group-mobility, a significant consideration on the battlefield, it implies that

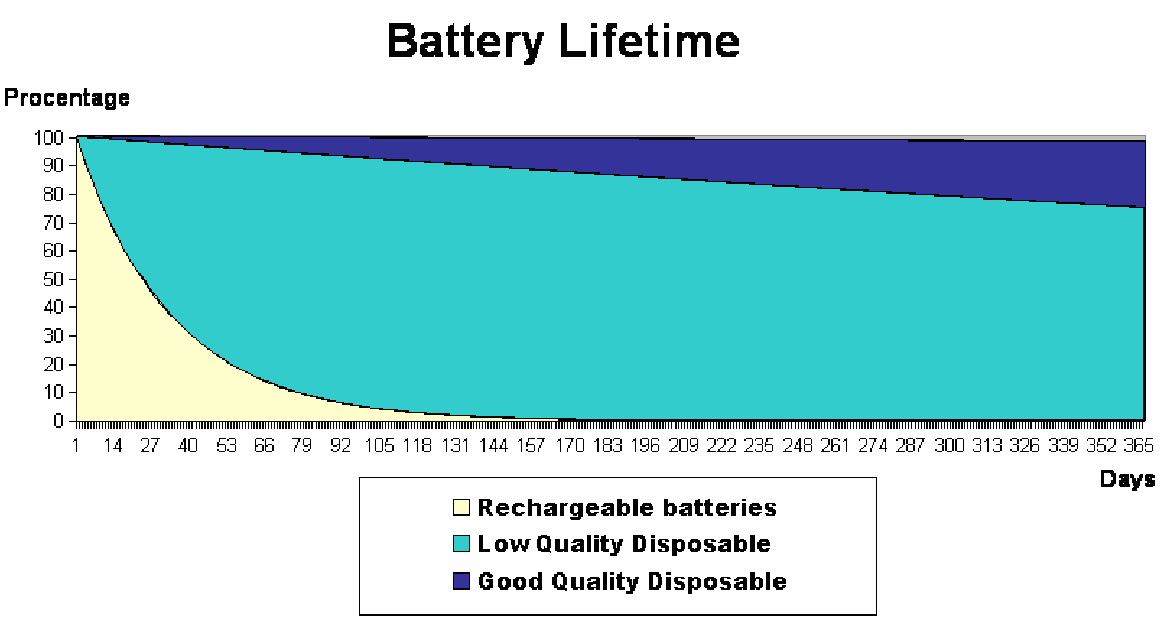


Fig. 2 Illustrating battery lifetime

future research in military-environment MANET requires repeating simulations for already considered solutions in order to further prove their usefulness on the battlefield.

The presented statistical data in [34] not only shows the problems involved in MANET research, but also questions the significance of previous research and their applicability to the military environment.
Simulation mistakes are not the only infeasible research when considering the military environment; the assumptions taken by the researchers would exclude their work for the MANET adaptations immediately. For simplification purposes, many researchers assume that all nodes are homogenous. However, [35] point that such an assumption avoids solving one of the issues - a possibility of asymmetric communication: node A may reach node B, but not the other way around. Such a situation can be influenced by different nodes' range, geographical location, or battery power shortage. A limited simplification of MANET constraints used to present research work can be acceptable; however, testing and simulation should realistically reflect the MANET environment, which due to its own high complexity provides limited space for simplicity and rejects solutions that do not obey all of the constraints. The following sections survey the actual physical constraints of the MANET environment.

4. Realistic Resource Constraints

Based on current technology, realistic constraints of power, memory and bandwidth are presented from a military application point of view. Recognition of the importance of such data should help to provide reliable simulation and testing, as well as to help understand the realistic physical constraints that should be taken into account in future research. Advancements in technology allows us to assume that in the near future some constraints may vanish, and we will able to assume that in some areas of MANET implementation we will be no more limited. In those areas, where we believe that there still exists an implementation challenge that resulted from limited sources available in the military environment, we propose a solution that should allow not only MANET network implementation, but will also make minor, the constraints for the electronic military equipment that soldiers carry on battlefields. The two-level ZigBee-4G design is proposed to lower the electrical power requirements.

4.1 Power

One of the constraints of mobile devices in the MANET environment is limited power supply. The issue of limited energy in mobile devices was researched in the last decade by electronic device companies that produced devices while trying to catch up to the fast expanding market requirements. New innovations and technologies allow us

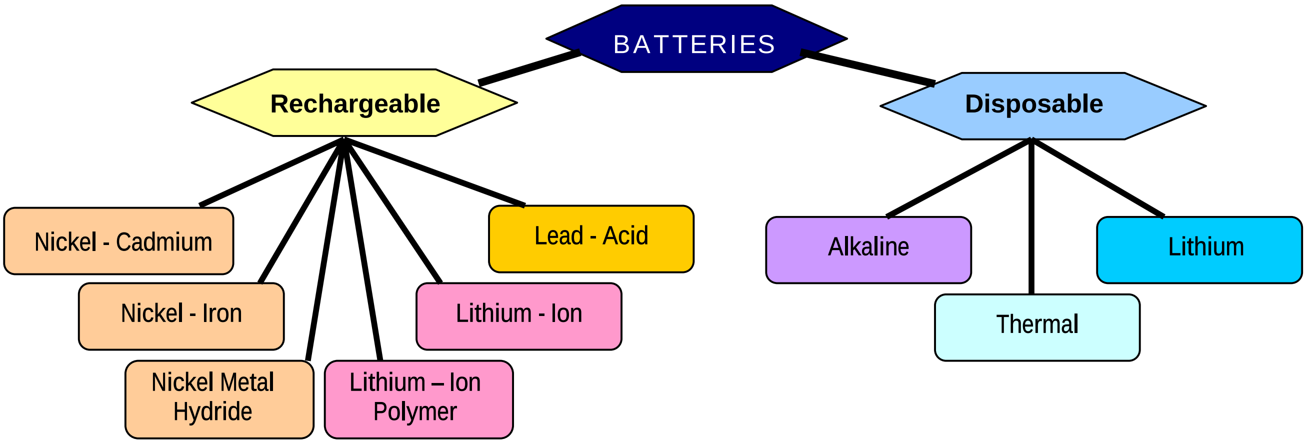


Fig.3 Different types of batteries

to assume that in the future, power should not be the mobile devices' constraint that would limit their development. However, in today's military MANET environment, we are limited to technologies that are present in civil mobile devices, and new innovations that when available, can be directly applied to MANET.

Two types of batteries, rechargeable and non-rechargeable, are used in electrical devices. For example, according to [2], non-rechargeable photo lithium batteries ($Li\text{-}FeS_2$) are the most efficient in HP cameras. [2] also recommends to use Nickel-metal hydride batteries (NiMH) which although the most efficient in the category of rechargeable batteries, are surpassed by $Li\text{-}FeS_2$ by 50-100%. What significantly distinguishes rechargeable and non-rechargeable batteries is the loss of their energy when unused. According to [2], 1-2% of energy per day is lost in rechargeable batteries, whereas non-rechargeable batteries almost do not lose their energy when not used. Electrical energy is also consumed

by nodes while no computation or network connection is required when nodes are in "standby mode," also known as sleep mode or hibernation. Working on low power Wi-Fi technology, the Nanoradio offers NRX700 Wi-Fi chipset with power amplifier and cellular RF filter built in, used for example in wireless network cameras working over 802.11b/g standards, which consumes 0.3mW in WLAN standby mode [57].

In the military MANET environment non-rechargeable batteries would be of higher importance and usefulness than rechargeable ones. First of all, military equipment is usually stored and kept prepared a long time before it is going to be used. Most of the technical devices are stored by the army while they wait for an emergency call. Therefore it is important that the battery does not lose its power while waiting on the shelf. Although the new technologies like WildCharge's pads capable of delivery of up to 90W of power and wirelessly charge mobile devices placed on the 0.1'' thin pads [54] simplify charging process, during an emergency there may be no time to recharge since immediate use is required. Secondly, since MANET is limited by having no existing or limited infrastructure, the ability to recharge is very limited. However, even if this would not be the case, the military environment in itself creates constraints that would demand providing a new non-rechargeable battery to powerless devices instead of letting the discharged batteries be recharged - a process that given present technology, would take too long to be feasible in a military environment.

While looking for optimal power sources for nodes in MANET let us look at the civilian market of mobile devices. Since customers' demands also places high constraints over the devices that they are willing to pay for, let us see what are the present battery problems in devices like mobile phones, laptops, and two-way radios that might have issues similar to the MANET environment. According to [1], Li-ion batteries are the best choice for cellular phones offering up to 1000 charge and discharge cycles in a two to three year service period. For two-way radios, [1] presents two solutions for substituting NiCd batteries that are dangerous for the environment: NiMH and Li-ion. The first one does not fit properly into two-way radio devices because it works on a discharge current of 0.5C whereas a discharge of 1.5A in 4W power transmission is required in the two-way radios. It is also suggested [1] that in general use of laptops, Li-ion batteries perform best. Also, according to research done by HP for Photosmart Digital Cameras where different types of AA Cells have been compared [2], $LiFeS_2$ batteries perform better than NiMH and much better than Alkaline batteries. Used by Apple in notebooks and iPods, Lithium-ion batteries offer the best possible performance by power up to 80% of battery's capacity in 2 hours of Fast Charge stage and in next 2 hours to complete full charge in Trickle Charge stage [56]. However, cell phones, laptops, and two-way radios use rechargeable batteries whose usefulness and effectiveness is questioned in MANET environment.

[1] also presents the idea of "smart" batteries that provide statistical information about state-of-charge (SoC) and state-of-health (SoH). This information may be crucial in a situation where particular nodes in MANET may be over consumed by additional maintenance work, for example routing, that will lead to drastic power consumption. SoC and SoH could prevent complete node's depletion and shift the work to a node with higher SoC and SoH.

Another concrete example comes from battery technologies used in present cell phones. According to [44], current 3G phones are capable of running for 45 hours in the "walkman mode". At the same time, they contain up to 2 Gb memory, with a 3.2 pixel camera, all of which weighs a mere 125 grams. However, the new iPhone by Apple offers up to 8Gb of storage, in up to 5 hours of Talk/Video/Browsing mode and in up to 16 hours of Audio playback mode.
A new solution to power constraints in MANET can be new technologies like the Geobacter Project [3]. The research group from the University of Massachusetts, Amherst, use Geobacter, bacteria known as *Geobacter metallireducens*, which by cleaning toxins provide electrical energy. As researchers hope, soon these bacteria should be able to provide enough power to run cell phones, radios, and laptops. At the same time, new optical computing technologies may lower power requirements by using the hybrid laser that soon will be capable to work on 20mA electric charge [49].

Power aware microarchitecture, maximization of power efficiency, and management of heat, that is produced as a result of increased computational power, are issues that current chip leaders, like Intel, have to consider while designing their products [61]. Another solution for power constraints of mobile devices in military environment are coming up technologies such as designed by mPhase nanobatteries, which are disposable batteries. Nanobatteries' revolutionary design uses "super hydrophobic characteristics of nanotexture circuses to control battery's internal reaction" and preserves energy for over 15 years by separating electrolyte from reactive metal when are stored [60]. Its small and flexible size supports nanobatteries candidacy for the military scenario implementation battery that will power up mobile 4G.

The power limitations of mobile devices are currently solved by introducing new types of batteries. In military MANET, the question is either to use rechargeable or non-rechargeable batteries that would fit to this environment best. However, more and more attention is focused on natural resources of energy. The Geobacter Project, although may seems very abstract right now, in few years may be one of the possible solutions to solve the problem of power constraints. The natural resources, also known as green energy that are coming from geothermal power, wind power, hydropower, and solar power, were already used as power sources for networking devices. Alternative to batteries, emerging power constraints solutions becomes more and more interesting since researchers put more effort towards creating low-power devices, and new technologies allows to produce chips and sensors that will limited the power consumption to mili-Amperes.

Fig. 4 This is how may look like a Freifunk's node.

The free community wireless local area networks in Germany Freifunk.net called ambitious plan of providing Wi-Fi access all over Berlin without using any cables. As a first step, the mesh network was implemented using B.A.T.M.A.N. (Better Approach To Mobile Ad-hoc Networking) routing protocol. While wireless network was successfully implemented without cables, members of the Freifunk were already considering throwing out power cables as well. The wireless source of electrical power had to be provided. The Freifunk's nodes were operating on 12V that could be collected using solar energy from solar cells. To keep receiving energy during cloudy weather and nights, the addition of wind turbine was proposed. In a result, a tree was designed with solar cell leafs and wind turbine on the top that would provide sufficient amount of energy to Freifunk's nodes.

4.2 Memory

Today, memory has become of the biggest constraints not just for the MANET environment, but more importantly, for any computer device. Especially, memory speed becomes a significant factor that upsets computer architectures, in that, although much success has been achieved in other areas computer development, much consideration is still being given to memory constraints. While processors keep offering new capabilities every year, when it comes to memory development, progress, even for mobile devices lags behind. Although new catch systems can offer up to 9Mb of 1.2 cache, in mobile devices, the cache is limited to 1 Mb L2, with Bus speed 400 MHz, and clock speed up to 1.5 GHz. [38] (A typical mobile use is defined as "Value mobile PC's")

In 2004, according to [32], a typical cell phone used up to 16Mb of SRAM, up to 128 Mb of Pseudo-SRAM, up to 128 Mb of NOR Flash, and sometimes additional 256Mb of NAND Flash. Newer and cheaper options offer mix of NAND Flash and LPSDRAM that significantly increase speed. Although these numbers have improved today, the satisfactory results are still far away. Main memory is simply too big, too expensive, and still not as efficient as customers would like.

To store data, Flash memory has become an interesting and optimal alternative. According to [33], Flash memory, like NAND, currently offers up to 8 GB of space and some companies are already introducing 16 GB. This memory size should offer a sufficient space to store non-volatile data in a cheap way; however, flash's speed is still too slow to allow fast computations.

The emerging nanotechnology, which already allows assuming a new break-down in memory development, presents new memory constraints that significantly will influence not only MANET's design but all computer industry. Named as one of the top ten emerging technologies [47], the Nantero's non-voltaire memory [46] called NRAM (Nanotube-based/ Nonvolatile RAM), offers significant improvement in speed and capacity comparing to currently available memories like DRAM, SRAM, or flash. According to [46], NRAM will work on less power consumption than present RAM of flash memories, and will be resistant to environmental forces. NRAM will not only replace current memory technologies, but also will allow to be implemented as CPU cache. As producers suspect, NRAM technology enables "instant-on computers, which boot and reboot instantly" [46].

The successfully tested 22nm NRAM Memory Switch by Nantero, may be improved by IBM physical scientists who believe that nanotubes measuring 1.5 to 2 nanometers in diameter can be fabricated. Unfortunately, the researchers still do not provide exact NRAM's data constraints that would allow setting MANET's constraints. However, already available information radically changes memory constraints of MANET environment, as well as other electronic devices.

4.3 Bandwidth

The bandwidth constraints in the MANET environment depend on technology of much utilitarian value. In the last two decades wireless technology was one of the biggest research areas, mainly motivated by introduction to the market of cell phones as well as wireless networks that became popular in homes and small offices. These two business areas motivated development of two types of wireless communication: cellular and Wireless LANs based on IEEE 802.11 specifications. Because MANET may contain different types of devices that should be able to communicate to each other in military non-infrastructure environment, both cellular and Wireless LANs technology should be applicable to MANET.

One of the questions regarding military MANET environment is the application of present military devices and their technical constraints towards future networks. If current devices can access MANET in a military environment, they will put the minimal constraints into the network. These constraints might not have to be final; however, they should allow wireless communication at least on the minimum requirements in the military environment.

Already available and used technology, that has also found

	Mobility	Range	Bandwidth
WiBro	250 km/h	5 km	50 Mbps
UMTS			2 Mbps
802.11g	5 km/h	0.05 km	54 Mbps
802.11n	5 km/h	0.1 km	540 Mbps
802.16a	5 km/h	70 km	70 Mbps
Mobile WiMAX	100 km/h	3 km	40 Mbps
802.20	250 km/h		1 Mbps
4G (mobile)	250 km/h	5 km	100 Mbps
4G	5 km/h	30 km	1000 Mbps

Fig. 5 Table comparing wireless networks

use in the MANET environment, is a factor that should be taken into account. The Michigan Public Service Commission [4] provides a comparison between different carrier technologies in mobile telephone interfaces. According to [4] GSM (Global System for Mobile communication) provides speed of 9.6 to 14.4 Kbps, HSCSD (High-Speed Circuit Switched Data service) up to 56 Kbps, GPRS (General Packet Radio System) 56 to 114 Kbps, EDGE (Enhanced Data GSM Environment) 384 Kbps, and UMTS (Universal Mobile Telecommunications Service) up to 2Mbps.

Offering desired technology for video conferencing, 3G (Third Generation technology of mobile phones) exists in 97 countries worldwide [8]. Transferring sound as well as other data, like video or maps, should be accessible to the military environment. Although UMTS was broadly accepted by business cellular companies, another 3D standard may be better applied in MANET environment – GAN/UMA (Generic Access Network a.k.a. Unlicensed Mobile Access).

The UMA, that was adopted by 3GPP (Generation Partnership Project) [9], is technology offering dual communication with cellular and wireless networks. According to [10] the advantages of UMA are IP network security, transparence and seamless mobility of cellular and wireless networks, as well as broadband, IP wireless, and WLAN support. The real effectiveness of UMA should be available soon, since NOKIA has already offered and is testing this feature in Finland [11].

Other available cellular communication standards, like HSDPA (High-Speed Downlink Packet Access) that offers 14.4 Mbps downlink and 2 Mbps upload [13] and HSUPA (High-Speed Uplink Packet Access) [14] – the most advanced stage of 3G that increased upload to 5.76 Mbps and lower end-to-end delays, were introduced to the market in 2006 or will be available in the beginning of 2007. In the USA Cingular Wireless already offers HSDPA and HSUPA.

When 3G technologies seems to satisfy the present market requirements, researchers and scientists are already working on tomorrow's telecommunication technology that according to [15] will move from Wideband Era to Broadband IP-based Era of 4G introducing WWWW (World Wide Wireless Web), and 5G that will allow wireless communication without limits.

The 4G technology may find implementation in the MANET environment; according to [15], the 4G is supported by IPv6, OFDM, MC-CDMA, LAS-CDMA, UWB (Ultra Wide Band) and Network-LMDS (Local Multiple Distribution System) technologies. OFDM (Orthogonal Frequency Division Multiplexing) would allow communication in the MANET military environment since according to [16] OFDM supports maintenance of adequate communications link where communication performance is hard to achieve. MC-CDMA (Multi-Carrier Code Division Multiple Access), LAS-CDMA (Large Area Synchronous CDMA) support OFDM communication in multi-user environment by allocating network resources for them [17], as CDMA can be connected to two or more base stations, and also supported by UWB that according to [18] allows small, low power and low cost transmitters that will be accessible underground and other places where OFDM is unreachable.

Some companies like NTT DoCoMo in Japan [19] are already testing 4G technology. According to [19], at a moving speed of 20 km/h, 4G prototypes can receive data at 100Mbit and even up to 1Gbit when static. More over, work by scientists at NTT DoCoMo using MIMO

(Multiple-Input-Multiple-Output) design, has enabled cell phones to communicate with more than one base station in range. Their 4G products should be available in markets by 2010.

According to [20] cooperative communication between cellular and wireless LAN networks is the future of wireless technology. More over, ad-hoc networks effectively integrate with 3G/4G, WLAN and the Internet, which makes it a desired solution for connecting many devices in larger networks and in wireless structures. As we can see, the future wireless networks will be made of any device that allows wireless communication. The introduction to the market, of 3G and newer technologies proves that in the military environment of MANET these devices will not be a mere addition to the network, but a necessity of MANET requirements in a few years.

Coming back to the present, another option in wireless communication, and widely available on the market and adopted in many situations, is the Wireless Local Network Technology developed and standardized by IEEE (IEEE

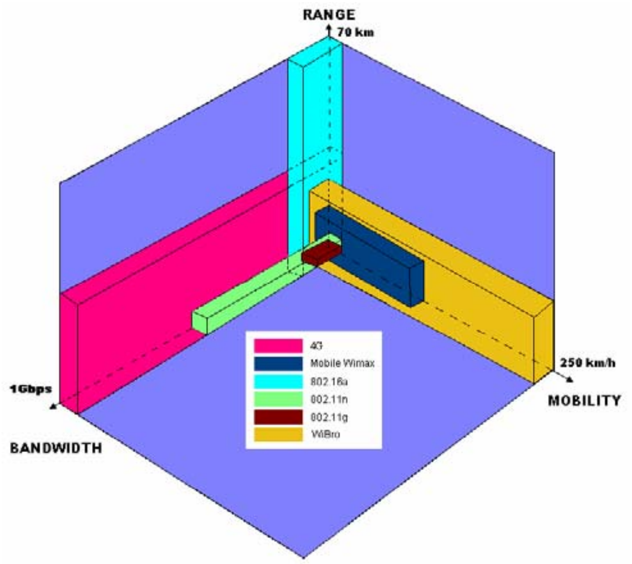


Fig. 6 Comparison of wireless standards

802.x). Based on a certain type of cellular architecture [21], 802.11 is a family of different types of over-the-air connections. In 802.11 LAN, each node connects to BSS (Basic Service Set) that is controlled by AP (Access Point) [21].

Already released 802.11a, 802.11b, and 802.11g protocols allow maximum data rate of 54, 11, and 54 Mbps respectively, and work in a range of 100 feet [23]. However, the new upcoming standards like 802.11n increase throughput support ITS (Intelligent Transmission Systems) and DSRC (Dedicated Short Range Communications) as in the case of 802.11p, support access of cellular devices into wireless networks – 802.11u, and can even directly support mesh networks like MANET – 802.11s. For example, in a range of 60 feet HDTV (High-Definition Television) can be accessed in home environment using 60 Mbps wireless networks offered by the Metalinks that offers the WLANPlus network over 802.11n standard implemented by dual-band chip-set [52].

The 802.11n standard, still in draft version, under development by TgnSync, WwiSE, and MITMOT [24] will offer transmission up to 540 Mbps at the 160 feet range. Called by [25] as Wi-Fi's next generation technology, 802.11n uses, like 4G, MIMO that allows connection to more than one receiver. According to [28], the new 802.11n standard will also improve the efficiency of the radio channel of 802.11 MAC which currently does not allow a bit rate in excess of 60%. However, according to [48] IEEE members working on the 802.11n are still far away from developing acceptable proposal that would either accept the already presented "draft-standard" or offer a new one. As [48] sources indicate, although 802.11n is still not finished, Intel is already working on implementation of the standard in the "draft-standard" version. Some companies like SMC already offers products with 802.11n Draft 1.0 standard that allows transfer rates up to 300 Mbps [58].

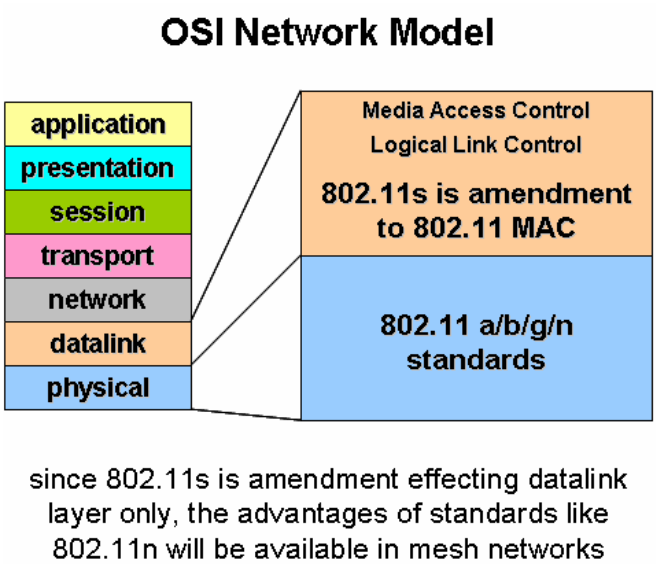


Fig. 7 802.11 Amendments.

The IEEE 802.11u project is already working on communication of wireless technology using 3G cellular technology [26]. In the future, 802.11u and 4G should provide standards for WWWW.

Finally, the most influential MANET environment IEEE standard, the 802.11s will provide direct support for mesh networks. Intel's proposition [29] not only presents ideas for automatically configured networks, but also to build prioritized traffic function. According to [30] 802.11s will configure networks based on WDS (Wireless Distribution System). The current proposition wants to build 802.11s on 802.11 a, b, or g standard. However, the Wi-Mesh proposal [31] for 802.11s includes 802.11n, management solutions of 802.11e,k, and security support from 802.11i. This year, pre-standard IEEE 802.11n will certify Wi-Fi products. The final ratification is expected in 2008 [15].

According to [12] new standards will significantly increase throughput to at least 75, 100, 480 Mbps for 802.16 (WiMAX), 802.11n (MIMO WLAN), and 802.15.3a (Ultra Wideband). According to [59], in a distance of up to 10 kilometers WiMax allows in static 40 Mbps capacity and in distance of 3 kilometers in mobility the bandwidth of 15 Mbps. As throughput increases, the range decreases. However, this issue can be solved by emerging IEEE 802.20 standard known as Mobile Broadband Wireless Network, sometimes also called as Mobile-Fi. According to [50] 802.20 offers low latency, transfer over 1Mbps, new MAC (Media Access Control) and PHY (Physical Layer) over IP and adaptive antennas, increased mobility to 250 km/h, and bands below 3.5 GHz globally supporting IP roaming and handoff. Unfortunately, the new version on WiMax created by IEEE 802.20 group working on access to Internet from trains and other fast-moving vehicles may not reach their goal of creating the final standard by the third quarter of 2007 because of political and economical pressures [53].

As we can see, wireless technology exceeds cellular technology in bandwidth; however, it is limited by shorter range and not as strong as cellular technology's signal strength which can be interrupted by home devices. The present technology is going to unify the best qualities of both wireless connections and create World Wide Wireless Web. The unification of both technologies offers more opportunities for MANET. It allows for the development of MANET military environment where present technology will be able to communicate with future cellular and wireless technologies. WWWW actually gives more flexibility than it puts constraints. Obviously, the physical limitations of bandwidth, range, infrastructure support still exist; however, today we are open to all available wireless devices and from them we can pick those that fit into the MANET military environment best.

According to [22] OFDM Based Wireless technology is the future for mobile wireless networks. OFDM that is part of the 4G and which will be part of future WWWW, is an example of realistic constraints for MANET. The beginning of 2007 will bring about development of wireless network standards particularly IEEE 802.11n and IEEE 802.11s that will directly influence this project. All introduced technologies, if not yet available, will be done so by 2010.

Optical computing can be another solution for bandwidth constraints. According to [49], scientists at Intel and at the University of California, Santa Barbara applying voltage of even 65 milliamps were able to produce a hybrid laser by combining induim-phosphide light emitter and the silicon laser. Although this new technology is still limited by temperature of above 40^{o}C, Intel's photonics technology lab scientists are expecting to increase working temperature up to 80^{o}C and lower electric charge to 20mA. In future this technology should allow up to Tbps transfer between computers as well as inside of them.

As we can see from the survey, from all three areas of research, the bandwidth is the one that is incredibly fast-developing offering connections that already exceeds our needs. Cingular, for example, the leader of UMTS/HSDPA technology on American market already offers downloads up to 1Mbps through their cellular networks. One of the first mobile devices that will use Cingular's mobile broadband communication is the HP Compaq nc6400 Notebook PC that can already support data rate of 3.6 Mbps over Cingular's networks [51]. Unfortunately this great bandwidth capacity dramatically decreases when range and mobility have to be increased. In military environment, these two factors range and mobility will be of significant importance and will define flexibility in creating mesh network without any backbone infrastructure. By merging wireless LANs and cellular technology, the fourth generation of cellular communication like UMB (Ultra Mobile Broadband) and 3GPP LTE (Long Term Evolution) will provide bandwidth of at least 100Mbps in high speed mobility, and in any environment.

Looking on the present trends in developing new wireless technology, the fourth generation of cellular networks with single interface to Wireless Local Networks, Wireless Broadband, Mobile Wireless Networks, and Short Range Wireless Network may not only solve broadband constraints but may also significantly simplify the implementation of networks. The general concepts of 4G can be presented in the list as follows:

- improved capacity
- increased number of users in the cell
- lower transmission costs
- connection with already existing systems
- lower latency
- based on IPv6 protocol, with packet switching
- single interface for all wireless connections
- increased mobility
- support for media applications
- seamless connectivity
- improved security
- improved and guaranteed Quality-of-Service
- global roaming of networks
- standardized open interface
- self-organizing networks
- fast response

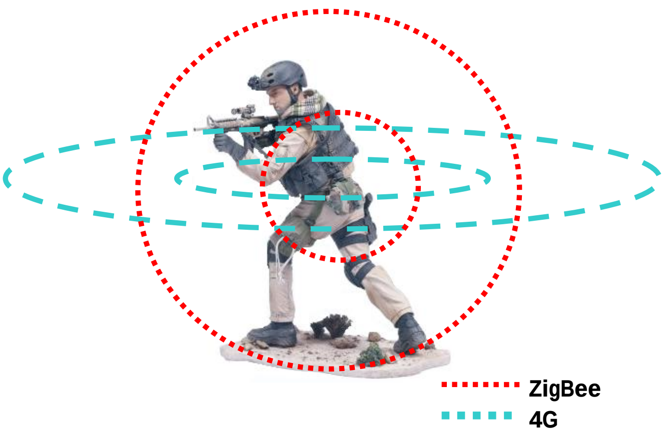
After evaluating resource constraints, the current technology advancements in memory storage and bandwidth wireless communication allows the assumption that in the near future, memory and bandwidth should not limit the development of military wireless networks such as MANET. The presented Flash Memory already provides appropriate amount of non-voltaire memory, which has a low production cost and is small in size. The upcoming fourth generation of wireless technology promises to provide a single access terminal to all kinds of wireless communications, which, while choosing the most appropriate one to achieve the finest possible bandwidth and QoS, will also offer satisfactory wireless communication that also allows us to believe that in the near future, bandwidth constraints should not be much of a concern for military networks.

However the power-constraint aspects of all electronic devices, and wireless networks as well, are still a concern of MANET's and 4G's implementation in the military environment, which particularly is lacking in electrical power on the field. More over, in the military scenario, usage of disposable batteries should be considered instead of rechargeable batteries because of the lack of accessible recharging terminals. As a result, a new design for low power consuming MANET network for efficient implementation in the military environment needs to be proposed.

5. ZigBee in Military Environment

Focusing on conservation of electrical energy in military scenario, a two-level wireless communication model is proposed based on the ZigBee protocol for close distance communication with personal devices, and 4G communication on longer distance for data exchange with nodes outside of ZigBee's range.

Fig. 8 Using ZigBee in military environment



ZigBee is the name used for IEEE 802.15.4 standard focusing of simple design for low rate data with over a year battery lifetime [63]. According to the IEEE 802.15 WPAN (Wireless Private Area Network) TG4 (Task Group 4), the new standard works on three date rates of: 250 kbps at 2.4 GHz, 40 kbps at 915 MHz, and 20 kbps at 868 MHz, using two types of addressing: short 16 bit, and IEEE 64 bit [63]. It also supports critical latency, fully reliable "hand-shaked" protocol, up to 50m range [65], power management, and automatic network establishment [63].

ZigBee Alliance, an association of companies all over the world such as Philips, Motorola, Intel, and HP, is also "developing very low-cost, very low power consumption, two-way, wireless communications standard [62]." Besides promoting ZigBee, the alliance is focusing on Zigbee's security, network and application specifications, "interoperability and conformance testing specifications [62]", as well as on the ZigBee's implementation.

The ZigBee Standard is built on three layers: Network and Application Support Layer, Physical (PHY) Layer, and Media Access Control (MAC) Layer. The application support consists of Application Support (APS) sub-layer that coordinates communication between devices and ZigBee Device Object (ZDO), which for example "determines the nature of the device [65]". ZigBee also supports three types of topologies: star, peer-to-peer, and mesh [65].

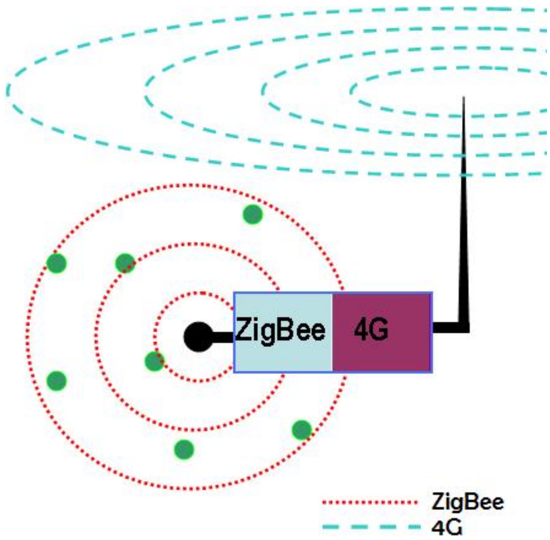


Fig. 9 Two-level ZigBee-4G design.

For military environment we propose two-level wireless communication with interface for ZigBee network implemented as the ZigBee Coordinator Node and with interface to 4G. The ZigBee Wireless Personal Area Network would cover the area around a soldier, or around a vehicle that participates in a military action. ZigBee Coordinator Node stores information about the network and forwards data to other networks [65]. In two-layer model for military purposes, the ZigBee Coordinator Node would established star topology network and communicate with two other available ZigBee devices: Full Function Device (FFD) or Reduced Function Device (RFD), whose implementation type would depend on the necessity transmitted data. When necessary to communicate outside of the WPAN network, the information would be forwarded to the 4G interface, and further using 4G. In near future, the implementation of 4G with MANET support provides the best possible network implementation, particularly considering the present type of war with terrorism where it is necessary to access any possible wireless network through single unit device, considering the security and the implementation issues of 4G, called as 4GM@4GW [66]. In this paper we assume that such successful implementation 4GM@4GW (Forth Generation Mobile at Forth Generation of Warfare) exist and we focus on WPAN network around the soldier or vehicle in military environment considering the electric power saving.

The successful implementation of ZigBee in soldier's WPAN could significantly economize the usage of electrical energy and by the same, lower the power requirements for wireless implementation in scarce in power setting such as military environment. In its design, ZigBee offers beacon network communication mode, which establishes scheduled, periodic transmission between Coordinator Node and network's node [65], allows additional power savings by allowing the network nodes switch into sleep mode for known periods of time. In the two level ZigBee-4G design, the wireless communication would used the lightest possible protocol (ZigBee) for communication within WPAN, and use powerful, but power hungry, 4G system for the only necessary communication that have to be established with nodes outside the WPAN.

Implemented in the military environment, ZigBee's WPAN needs to provide some kind of security that would allows safe communication within the network between network's nodes and the Central Node. For military purposes the following situation is proposed. Since every soldier and vehicle is located in a secure environment such a base station or a camp, the key exchange between network devices can be established right before the military action initiates, assuming that such a secure area exists, where key exchange may safely take a place.

As a result of the resource constraints evaluation for MANET network, which shows the scarce power resources obtainable in military environment implementation, the two level ZigBee-4G design was proposed to lower the power consumption within the WPAN soldiers or vehicles networks that will also collect and forward appropriate information outside of the local network using 4G when it is necessary. In the military scenario presented next, the ZigBee-4G design will be considered, and the possibility of secure wireless communication implementation will be presented.

6. Security in the military scenario

The presented memory, bandwidth, and range limitations of mobile devices create physical constraints for devices that are going to be used in military environment. The characteristics of the military scenario are additional aspects that limit the effectiveness of nodes communicating on enemy's territory. Considering the military scenario, the technical limitations may require a correction when additional factors such as weather, land topology, and type of military action, will be considered.

The presented physical constraints, mostly collected from research organization working over technology that can be successfully sold to customers, assume usage of mobile devices limited by mentioned physical constraints in a civil environment, where business companies can provide adequate technical infrastructure to provide sufficient service. This often requires mounting additional antennas in very urban areas, or in mountain land. Although MANET is a solution to create network communication over the limited infrastructure, the additional components from supporting business are always the significant support that can solve technical issues which normally would be too expensive to use, or require additional components to support the network's backbone.

The military scenario is characterized by not only the lack of business funds and infrastructure to support connection, but also includes enemies, who sometimes are well informed and prepared to use DoS (Denial of Service) attacks on MANET network. Enemies are also developing new techniques to prevent wireless communication of army forces. In military environment a successful attack on MANET include not only interception and if neccesary decryption of data, but Denial of Service Attacks as well.

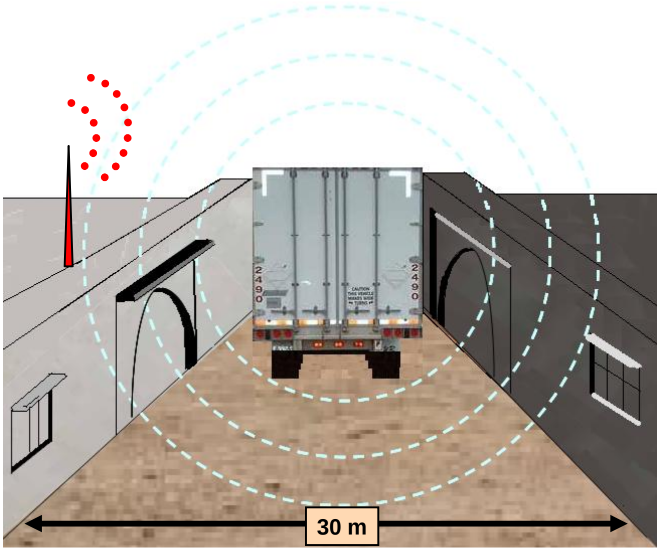


Fig. 10 WPAN security concerns.

Because ZigBee is a short range wireless communication of a light weight protocol, a light weight security should be implemented. One can argue that since ZigBee-4G focus on low power consumption ZigBee will be more efficient without aplied security. If ZigBee would be implemented in home environment, where it is very unlikely that someone else other than a home resident would be in ZigBee's range, or if the privacy and importance of data transmitted between home devices would be considered, which obviously do not require such high privacy and security, than in such a situation additional security could be unnecessary. However, in the military scenario, no data is unimportant for army forces as well as for enemies, and as the Figure 10 shows, it is possible for a vehicle, soldiers, or soldiers traveling on the vehicle, to be in such an urban territory, where the enemy can hide and try to access the ZigBee's WPAN networks.

The ZigBee Alliance proposed the security services [62] "for establishment, key transport, frame protection, and device management" for the Medium Access Control (MAC) layer, the Network (NWK) layer, and the Application Support Sublayer (APS) [62]. ZigBee Alliance provides cryptographically secured communication between different devices and non-cryptographic communication between different stack layers in the same device. As a result, the same key is used between two devices, no matter on what layer they are communicating with each other. The security architecture proposed by ZigBee Alliance for 802.15.4 standard base on implementing one, out of eight available, security suits with an appropriate combination of data encryption, frame integrity, and access control services.

The popular public key algorithms that are used to establish symmetric key communication may not be feasible in power constrained military environment because of their computational requirements. If it would be necessary to use public key encryption in the military environment, than a light weight encryption and authentication scheme would need to be used. Zheng et al. proposed a DPK (Derivable Public Key) that "significantly simplifies the public key operations and reduces the related cost by eliminating the need for distributing and storing public keys other than the one from the trust centre [64]."

ZigBee Alliance defines for every WPAN network a single Trust Centre that provides services of trust management, network management, and configuration. In our ZigBee-4G proposal, the ZigBee Coordinator Node, which is implemented together with 4G interface, would take the role of the network's Trust Centre. If the usage of public key would be necessary to implement, the DPK would be used. However, considering military environment, the usage of the only symmetric key encryption should provide enough security for the soldiers and vehicles WPANs, and also lower the computational requirements of these devices, which would further allow saving more electrical power. The symmetric keys would be manually distributed between devices before a military action would take place.

The distribution of the symmetric keys that takes place before the military mission starts could be done in two different ways. One scenario assumes that each soldier received a whole set of network devices manufactured together with pre-loaded keys. In such a situation a soldier would not have to care about wireless security between devices in possession, but only be sure that all of them come from the same package containing the set of devices with the same symmetric key. A second scenario allows the different components of WPAN network to be produced by different manufacturers. However, in such a situation the symmetric key has to be manually entered into all the devices that become the WPAN's nodes.

7. Conclusion and future work

This paper presents current MANET research concerning routing protocols, proxy technologies and middleware software stressing the significance of realistic physical constraints for military MANET. Current power, bandwidth, and memory constraints are presented, as well as new emerging technologies are suggested for consideration with regard to MANET military constraints.

New technological solutions already allow accessing networks while devices are in high speed motion: in a car or in a train, but this often requires complicated infrastructure. Already available bandwidth allows text, voice, and TV communication in high quality over wireless networks. Military MANET constraints are example of simple present technology limitations which can be considered in today's simulations and real-life implementations [7]. The emerging solutions for MANET's constraints may show insignificance of some parts of research where improving some aspects may not be necessary in the light of emerging technology.

Analyzing present physical constraints over MANET network, it is impossible to predict which solution will take the leading role in defining the physical constraints in few years, although, power constraints seems to be the most limiting factor in defining physical constraints in military MANET environment. Everyday emerging new technologies offer better solutions that increase capabilities of personal devices by decreasing their requirements in terms of power consumption, memory usage, and connection bandwidth, and at the same time moving away boundaries of physical constraints. More power is available every day, more data can be sent and received, and more memory is available.

While memory and bandwidth constraints can be neglected, the limitation of available electrical power in military environment demands new wireless network designs that will take into consideration power conservation. With regard to power constraints, the two-level ZigBee-4G design for Wireless Personal Area Networks is proposed. The design uses the lightweight protocol for wireless communication based on the IEEE 802.15.4 standard that establishes wireless communication with all nodes that are present on soldiers or in short range vehicles. The wireless communication is managed by the Coordinator Node, which when necessary forwards messages outside the WPAN networks using the 4G interface. The 4G interface allows effective, but power-costly, wireless communication and is also a member of the MANET network. The WPAN security is implemented by establishing a symmetric key which is either preloaded by the manufacturer or manually entered by soldiers before the beginning of a military mission.

Acknowledgments

This research was sponsored by the U.S. Army Research Laboratory and the U.K. Ministry of Defence and was accomplished under Agreement Number W911NF-06-3-0001. The views and conclusions contained in this document are those of the author(s) and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Army Research Laboratory, the U.S. Government, the U.K. Ministry of Defence or the U.K. Government. The U.S. and U.K. Governments are authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

This research was also partly sponsored by IT Scholarship Program supervised by IITA (Institute for Information Technology Advancement) and Ministry of Information and Communication, Republic of Korea.

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