

4G and MANET, Wireless Network of Future Battlefield

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Abstract - *The era of new wireless communications is upon us. Eventually it will penetrate into our daily life and change the way we live just like many technological innovations whose original research came from the military needs. In this paper, we investigate future wireless network especially in the hostile military environment. By combining two hottest wireless network topics, 4G (the fourth generation of cellular communication systems) and MANET (the Mobile Ad-hoc Network), we explore potentials as well as foreseeable challenges to the wireless communications in the future battlefield..*

Keywords: 4G, Mobile Ad-hoc Network, Military Wireless Network, MIMO

1. Introduction

The fourth generation of cellular communication systems, generally known as 4G, is the emerging technology of future wireless networks. For the past years, many researchers and scientists from all over the world have been working on projects funded by governments and business institutions whose goals are efficient wireless networks by merging all current technologies and adapting new solutions for the enhanced telecommunication which provides superior quality, efficiency, and opportunities where wireless communications were not feasible. Some researchers define 4G as a significant improvement of 3G where current cellular networks' issues will be solved and data transfer will play more significant role. For others, 4G unifies cellular and wireless local area networks and introduces new routing techniques, efficient solutions for sharing dedicated frequency band, and increases mobility and bandwidth capacity.

Like 4G project, the MANET (Mobile Ad-hoc Network) is also in a developing stage. While defining the MANET standard, the Internet Engineering Task Force is working on routing techniques, like Ad-hoc On-Demand Distance Vector (AODV) defined in RFC 3561 [2] and Optimized Link State Routing Protocol (OLSR)

defined in RFC 3626 [3], allowing self-configuring network of mobile nodes with routing capabilities [1]. MANET standardizes the static and mobile techniques of creating mesh networks using available wireless technology.

Currently, 802.11a/b/g/n wireless networks defined by the IEEE standards are being used at homes, offices, and also could be found in the initial MANET infrastructure. Thus, what limits cellular networks and WLANs will limit MANET as well. On the other hand, any solution that can increase capabilities of wireless networks can influence capabilities of MANET as well and furthermore could mitigate serious issues like hidden terminal problem and fading [4].

New wireless communication technologies are expected to significantly influence the design and implementation of MANETs in the military environment. Since the future technology combining wireless local networks and cellular networks is more and more being referred to, and defined as the fourth generation (4G) of communication systems, it is critical to understand the meaning of 4G and its potential in influencing wireless networks, particularly MANET. Since we should assume low infrastructure of the mobile ad-hoc networks in the hostile military environment, 4G could be an answer to offer significant solutions for mobile MANETs to achieve high quality transmissions and constant connectivity. However, the implementation of 4G may be significantly more complicated than in the civil environment due to the unique specification and requirement of the military environment. We introduce the term 4GM@4GW that describes possible issues of the forth generation of cellular network implementation in the forth generation of warfare.

This paper is organized in the following way: Section 1 introduces the paper. Section 2 presents general overview of the 4G and its most probable design and capabilities. The following sections describe the definition of 4G as a significant factor influencing wireless networks. Section 3 details how 4G technology might influence networks. Section 4 defines physical challenges of 4G MANET implementations; Section 5 highlights implementation issues of 4G in the mobile military environment of the forth generation of warfare

by introducing 4GM@4GW terminology. Finally, Section 6 concludes this paper and describes future work.

2. 4G Overview and its Potentials

4G stands for the fourth-generation cellular network. Although it is generally agreed that 4G is going to offer better communication technology than 3G, it is still undefined as to which areas should be really improved upon, and in which ways, from 3G. Researchers are often pointing towards integration whereas business institutions are working on upcoming technologies that will make 4G more attractive to the business community by implementing it more customer-friendly. This section presents different perspectives on how 4G is defined. Later, we will investigate how the fourth generation of mobile wireless networks (4GM) can be implemented in the modern military environment known as the fourth generation on warfare (4GW). We introduce term 4GM@4GW to discuss issues of implementing presented technology in the military mobile environment.

New support for mobility is the primary concern of Hussian *et. al.* [6] and they pointed out insufficient 3G mobility constrained by bandwidth that should be significantly increased. According to them, the significant progress that 4G can achieve in the area of mobility is unifying different and currently separated environments into a single fixed OWA (Open Wireless Architecture) that will achieve high connectivity by accessing all kinds of networks. Invented by the Delson Group's R&D division, OWA is a project working on developing a unified global standard of mobile communications to achieve global mobile access, high quality of service, with a single fundamental component allowing easy transmission of all kinds of data [7]. Providing single terminal that will effectively access the best available internet connection will increase and speed up device usability under 4G.

Integration is the key concept in defining 4G capabilities [8] since we should support all kinds of multimedia by offering single access to all wireless networks. Understanding the significance of unifying Wi-Fi, WiMax and Cellular networks into one product, Woerner and Howlader [5] proposed that the most important factor of 4G will be "seamless integration of wireless networks" based on flexibility of the software radio technology, with improved bandwidth capacity, and improved routing techniques allowing multi-hop peer-to-peer networks. Due to the lack of single military scenario where and how 4G will be used, it is critical that future wireless technology will be capable of effortlessly accessing all kind of radio communications.

Bauer *et. al.* [21] addressed that enhanced cellular range and capacity, supported by Wi-Fi and WiMAX networks is the vision of 4G [21]. However, considering the fast development of WiMAX networks, and the increasing range of Wi-Fi standards, they argue that these new wireless networks can in the future substitute cellular networks such as the current 3G. They also addressed that it is "misleading" calling the evolution of cellular technology in terms of generations because this would "suggest a linear progression" which is not the case. Finally, they also evaluated business opportunities of 4G pointing out on establishing a global standard, along with open architecture, and supporting multiple interfaces all over the world, as the keys to economical success.

DVB (Digital Video Broadcasting) is the "global standard for the global delivery of digital television and data services [20]." Researchers see DVB-H (Digital Video Broadcasting - Handheld) and DMB (Digital Multimedia Broadcasting) as additional component of 4G providing video transmission to mobile devices. Understanding technical requirements of soldiers fighting on the battle-field, we believe that DVB can become a significant utility for army by providing necessary information such as soldiers' view and access to maps and immediate satellite pictures.

There are two paths leading toward each other whose goal is 4G. One path defines the evolution of 3G cellular systems into more advanced 4G technology that will recognize and be supported by Wi-Fi standards and upcoming wireless networks technologies. The other path successfully deploys high bandwidth and introduces high-speed mobility emerging from currently popular Wi-Fi technology and upcoming standards such as WiMax 802.16 supported by mobility amendment 802.16e and additional projects like 802.20 considering mobile broadband wireless networks. For the second group of people leading toward 4G, cellular networks are additional supporting component offering complete integrity with all available wireless connections.

Steer [9] addressed 4G is officially designated by IEEE as "Beyond 3G." Characterized by wireless broadband with over 100Mbps mobile capacity and 1Gbps stationary bandwidth supported by OFDM, MIMO, and software defined radio, Steer [9] presents new 3G's components that will upgrade it up to 4G. The idea of upgrading 4G is shared by two other groups working on the next generation technology 3GPP and 3GPP2 developing new versions of UMTS and CDMA2000 cellular systems respectively.

After introducing HSDPA (High-Speed Downlink Packet Access) in release 5, HSUPA (High-Speed Uplink Packet Access) in release 6, and HSOPA (High Speed OFDM Packet Access) in release 7, the 3GPP group project is working on release 8 – the UMTS (Universal Mobile Telecommunications System) Revision 8 LTE

(Long Term Evolution) that will introduce 4G on UMTS foundations [10]. The 3GPP plans presented in Technical Report (TR) 25.913 that are going to be concluded in September 2007 [10] expects cell coverage between 5 to 30 km, latency below 100ms, 100 Mbps/50Mbps downlink/uplink data rate within 20MHz spectrum allocation, high performance mobility up to 120km/h that between networks can be increased as much as up to 500km/h. The same report signifies the importance of IP-based networks with support of MIMO and OFDMA. Currently Ericsson's antennas allow 144Mbps transmission [22].

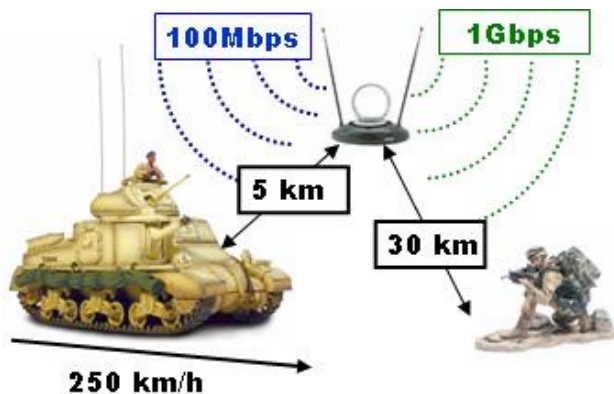


Fig.1 4G in military environment

Based on IS-95 (Interim Standard 95), CDMA2000 is third generation telecommunication standard that became foundation for 3GPP2 (Third Generation Partnership Project 2) project introducing 4G known as UMB (Ultra Mobile Broadband). Like UMTS 8 LTE, UMB will be supported by MIMO and OFDMA. With full mobility, UMB offers over 100 Mbps transfer using beam-forming signal processing technique from smart antennas [11], which although highly complex and still significantly costly after integration with MIMO allow high data rates particularly in scattered environment [12].

Whereas 3GPP and 3GPP2 are upgrading 3G technology up to 4G, the groups like the WiMAX Forum are developing solutions that increase capabilities of wireless local networks. An organization of over 400 leading operators called WiMAX Forum is working on technology offering wireless alternative to DSL and cable providers based on IEEE 802.16 and HiperMAN standards called WiMAX (Worldwide Interoperability for Microwave Access) [13]. While stationary, within the cell radius of 10 km, WiMAX Forum Certified™ systems allows 40Mbps transfer, and 15Mbps transfer, in 3km radius, while mobile, using OFDMA and advanced antenna techniques with MIMO [13]. The bandwidth

capacity can be increased by lowering the range, and vice versa.

WiBro (Wireless Broadband) is the Korean alternative to WiMAX. Offering mobility of up to 60 km/h, with service coverage up to 1 km, handoff less than 150 ms, maximum download 3 Mbps and maximum upload 1Mbps, WiBro is an important support to mobile wireless research projects [17]. Cooperating together, IEEE 802.16, WiBro, and HIPERMAN, will create single version of WiMAX based on American, Korean, and European developments of broadband mobile wireless networks.

Considering mobility of future 4G technology, two additional working groups IEEE 802.16e (Mobile WiMAX), which is the amendment to IEEE 802.16a, and IEEE 802.20 (Mobile Broadband Wireless Access) provide new wireless broadband services. Although similar because both goal at low latency on packet architecture with at least 1 Mbps transfer [18], [19], 802.16e and 802.20 target on different speeds of nodes. The 'e' amendment maintains the 802.16 achievements adding vehicular mobility [18]. The networks' access from trains traveling with speeds up to 250 km/h will be possible using mobile broadband wireless access defined by IEEE 802.20 [19].

Looking back on different paths leading toward next generation communication system, 4G emerges as a puzzle of many components that when connected together properly, complement each other's technological holes such as mobility, range, or bandwidth creating the 4G picture that provides global, single, and a simple standardized way of accessing it such as puzzles have one, by everybody known, way of putting them together. The Pioneer and Inventor of 3G/WiFi Convergence Systems and Technologies, Top Global USA, Inc. created the first such 4G picture, the first mobile router that links 3G/4G Cellular and Wi-Fi networks. Providing seamless routing and secure connectivity, Top Global's router maintains connection in moving vehicles with 802.11n, HSDPA, and WiMAX wireless access points simultaneously [23].

In this section, we observed how 4G technology will simplify implementation of wireless networks and at the same time increase mobility, bandwidth and range on the radio signal in the civil environment. As we will investigate in the later sections, it might be more difficult to achieve same successful results from 4G in the military environment compared to the civil environment in a metropolitan area.

3. Networks with 4G

Although there are different ideas leading toward 4G, some concept and network components frequently come up as a supporting and significant solutions that help achieve progress toward 4G. In this section we are going to investigate and explain technological innovations such as MIMO (Multiple-Input Multiple-Output), OFDMA (Orthogonal Frequency Division Multiple Access) and HIP (Host Id Protocol) that could significantly increase security, mobility and throughput of 4G.

Imagine that you can hear better what you want to listen, and don't hear what bothers you, just by pointing out where message and noise are coming from. Beamforming that is the significant concept of MIMO (Multiple-Input Multiple-Output) allows you do just that using smart antennas system. But that's not all what MIMO has to offer. Spatial multiplexing, achieved by independent simultaneously working antennas, increases bandwidth capacity by modulating and transmitting signal through many paths [15]. Using space-time coding, reliability is improved. MIMO achieves great success thanks to multiple antennas that allows simultaneous directional transmission of two or more unique data streams sharing the same channel. Increasing speed and range, MIMO is already accepted by researchers as one of the main components of projects such as WiBro, WiMAX, WLAN, 802.11n, UMTS R8 LTE, and UMB.

Datacomm Research Company [25] proposed the simplest way to implement MIMO is by sharing frequency using OFDM, that together significantly can increase performance by extending range, boosting speed and improving reliability. Together with MIMO, OFDMA is another component of 4G that as the alternative to CDMA, promises high data capacity and spectral efficiency. OFDM (Orthogonal Frequency-

Division Multiplexing) is the modulation scheme which divides allocated frequency channel into many narrowbands guaranteeing mutual independency between subcarriers such that there is no interference between them; signals are orthogonal [24].

To share bandwidth between many users, the obtained subcarriers have to be distributed between users using diversity in frequency, time, space or code [24]. Lawrey [24] proposed new technique by allocating subcarriers between multiple users by one of the five methods:

- distribution by fixed frequency
- randomly hopped subcarriers
- distribution using TDMA
- by spreading subcarriers in a comb pattern
- by adaptive user allocation

4. Power Challenges of 4G MANET

When processing speed doubles every 2 years (Moore's Law), another significant component of wireless devices limits their usage in the military environment - a battery. The fourth generation of wireless technology offers increased bandwidth, mobility and the signal's range. Increasing the signal power, a device requires more electrical power that will be consumed during signal transmission. The amount of energy currently stored in batteries needs to be increased to utterly benefit from the fourth generation of mobile wireless network implementation. More sophisticated, with additional routing protocols and security enhanced, wireless nodes require also a lot of computational power. Although the processors speed increases and its they turn into lower power consumption by introducing nanometer processor technology, the software requirements become more and more complicated requiring faster hardware (Wirth's Law), and more electrical energy.

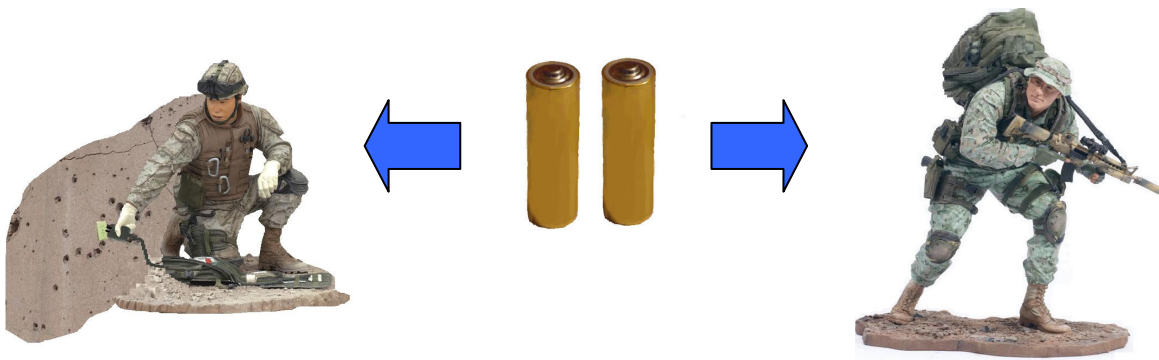


Fig.2 The batteries used on battlefield will influence the soldiers' mobility

Today two kinds of batteries are available for mobile devices: rechargeable and non-rechargeable batteries. Rechargeable batteries, such as nickel-cadmium, nickel-iron, nickel metal hydride, lithium ion polymer, lithium-ion, and lead-acid, are characterized by ability to restore their energy through application of electrical energy. Disposable batteries: alkaline, thermal, lithium, are used once and discarded. However, when disposable batteries are unused they can lose less than 5% of their energy during one year, whereas rechargeable may lose over 90% of stored energy just after 100 days. While a military action becomes organized and prepared, technical equipment, stored in magazines, awaits its usage. During this time, it is critical to ensure that once military equipment gets prepared and stored, it will keep its ability to rapid usage for long period of time. To allow rapid ready to mission state of all mobile devices, it is important to ensure that batteries will last for more than 100 days while stored on a shelf.

We present a single military scenario to show the importance of considering the power constraints of 4G MANET. The important aspect of 4G MANET in military environment is the fact that soldiers will become independent units where everybody will be able to communicate between themselves as well as with the headquarter using all possible means of wireless low infrastructure communication. Increased soldiers' mobility as well as quality of communication increase the total weight of equipments that soldiers have to carry with them on battlefield. The increased amount of technology increases the minimum amount of electrical power that has to be provided during military action for every soldier. Whereas 4G mobile devices implemented for military environment should not significantly increase the soldier's weight, the batteries weight might do so.

Imagining that 4G MANET implementations, as well as all necessary military technical equipments were provided during a military action we present in the Figure 2 two situations that might take a place. In one situation, a soldier will be required to carry overwhelming amount of batteries that will significantly decrease his mobility. On the other hand, unacceptable weight of batteries was solved by introducing rechargeable batteries. However, in this case, the soldiers' mobility becomes limited as well.

The presented two scenarios show two extremes that will never be acceptable as real life implementations of 4G MANET technology in military environment. However, the increased quality of communication and mobility, achieved by the forth generation of wireless technology, can paradoxically be abandoned in military environment because of consuming enormous amount of electrical energy that will be supplied either by

rechargeable or non-rechargeable batteries, which in result will decrease soldiers' mobility. The solution for this problem can be new batteries designs and wireless technology that will lower power consumption.

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 [30]. 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 [29]. Its small and flexible size supports nanobatteries candidacy for the military scenario implementation battery that will power up mobile 4G.

5. 4G MANET Implementation

From earlier sections, we investigated many faces of the forth generation of cellular network. Its final definition as well as main concepts influencing the progress of wireless network technology toward 4G portrays the future society living in utopia of constant access to all kinds of information through wireless communication. Someone may think that such technology is already accessible while walking on the streets of New York. New Yorkers, with all kinds of technical equipments that they are carrying, such as cell phones, PDAs, and laptops, are able to access information through cellular networks or local wireless networks from the free public hotspots installed by NYCWireless community or networks in homes, offices, or restaurants and bars. New York needs single terminal allowing access to all kinds of wireless technologies and business support that will take a profit, to step up into 4G. However, unlike commercial environment, 4G implementation and secure constant connectivity may require tremendous work in a military environment.

The next generation of wireless technology requires understanding the future of warfare: the 4GW. 4GM@4GW is the idea of implementing the forth generation of wireless technology into mobile ad-hoc network in the next generation military environment. To understand this concept better, we will first explain the 4GW term defined by William Lind, an American expert on military affairs, as the theory of the Forth Generation War.

Lind [27] addressed the history of warfare can be divided into four generations. The first generation of warfare is characterized by significance of man power; the winner had simply more soldiers. The second generation focused on firepower. During World War I, armies were staying on the line, shooting toward each other, and the winner was the one who could survive the hell by having access to more artillery. Focusing on speed and coordination, the idea of highly mobile military introduced by the Nazi Germany during World War II as flash war (ger. Blitzkrieg), illustrate the third generation where “attack relied on infiltration to bypass and collapse the enemy's combat forces rather than seeking to close with and destroy them” [26]. The news coming from Iraq and Afghanistan show examples of the forth generation of warfare known as 4GW, which is characterized by vanishing line between peace and war, and no existence of battle front [26]. According to [27], the 4GW “includes all forms of conflict where the other side refuses to stand up and fight fair.”

Additional technological key components of 4GW question the success of 4G MANET in military environment. 4GW is not only the new way of moving army forces using new artillery, but also the worldwide real-time information revolution, supported by all kinds of new technology, with cyber and net wars [27]. In the world of priceless information, the transmission medium of data becomes a target of attack during any kind of conflict. It is a misconception that addition of efficient and unbreakable cryptography to 4G supported by MANET's routing protocols will be enough to create professional wireless communication for army. The first significant point of the 4GM@4GW is to aware about the wide spectrum of terrorist technological activity by an enemy and to indicate the possible actions done by the enemy that can prevent successful implementation of future wireless networks in military environment.

4GM@4GW will be supported by 4G using increased mobility, range and bandwidth, single terminal connectivity with all already existing military equipment, possibility of using any present technology maintaining communications on the territory of action, and supported by MANET's mobile mesh routing in case of lack infrastructure. At the same time, 4G(M@W) will be twisted by technical limitations, natural-geographical constraints, possible breakings of encryption code, and DoS (Denial of Service) attacks.

Technological limitations defined as physical constraints in terms of bandwidth, memory, and power, are the first significant point on the list of issues in 4GM@4GW. This paper defines the possibilities of increasing bandwidth using the forth generation of wireless communication. Currently accessible on market different kinds of memory allow us to assume that sufficient and low cost memories, such as flash drives,

should fit into military environment. However, the important issue arises from supplying military mobile electronic devices by sufficient amount of power that is dependent on: how 4G is going to be implemented, what routing protocol will be applied, in what urban-geographical environment missions will take a place, and finally the duration of missions.

Natural geographical constrains are another issue that can influence 4G(M@W). By increasing range and bandwidth, 4G lowers the possibility of existence of routing problems between nodes in MANET network, such as hidden terminal interference and signal's fading. But at the same, the shape of the land may limit the benefits of using 4G. For example, 4G in military environment will achieve different results when used on the deserts of Iraq, in Afghanistan Mountains, or in some very urban city with metal-concrete and electric barriers. This brings to the question if a single implementation of 4G(M@W) can success in all geographical environments? In 4GW where army forces have to be ready to combat in any time and in any place all over the world it would be critical to use one single model of a device that will be able to provide sufficient communication during military action without major dependencies on the shape of land.

Comparing to the implementation of 4G in the civil environment, 4GM@4GW is also constrained by enemy's action preventing successful communities of army forces and technological devices left on the battle field by enemies for the purpose of disrupting the wireless communication. Such an activity does not have to focus on decrypting information that is sent through air, but simply on preventing information to reach the soldiers by using DoS attacks. In many cases, successful DoS can be more important that decrypting information because of its immediate influence on the army's condition.

6. Conclusion

The forth generation of cellular system will provide single interface to all kinds of wireless networks allowing participating nodes to access to the network through cellular, wireless LAN networks, and new protocols such as IEEE 802.20 and WiMAX. But, successful and safe implementation of the forth generation of wireless technology into the mobile ad-hoc network for the next generation military environment might face tough challenges. It also can be interrupted due to the significant differences between the civil and military environment. Physical and technological constraints, geographical limitations and DoS attacks are some of the foreseeable challenges. By putting all possible technological advances together from 4G and MANET,

we tried to set an example for future battle-field in this paper.

The era of new wireless communications is upon us. Eventually it will penetrate into our daily life just like many technological breakthroughs whose original research came from the military needs. Automatic high-way traffic control system where vehicle equipped with sophisticated embedded communication chips can enter and leave from the infrastructure dynamically will be one example among many potential applications from 4G and MANET combined scenario.

The future work includes: define physical constraints for military mobile devices, simulate the effectiveness of MANET's routing protocols in 4G environment to find the most optimal protocol for the 4GM@4GW.

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