4GM@4GW: Implementing 4G in the Military Mobile Ad-Hoc Network Environment

Marcin Szczodrak[†], Jinwoo Kim[†], and Yuncheol Baek[††]

John Jay College of Criminal Justice (The City University of New York), New York, NY, USA[†]
Division of Computer Software, Sangmyung University, Seoul, Korea[††]

Summary
The fourth generation of cellular communication systems, generally known as 4G, and the Mobile Ad-hoc Network, generally known as MANET, have been the subject of the much research for the past several years for their unique potential to realize today's and future challenging wireless networking needs. In this paper, we investigate potential synergy from 4G and MANET specifically in the perspective of military environment for the future battle-field and also address their foreseeable limitations and challenges.

Key words:
4G, Mobile Ad-hoc Network, Military Wireless Network, 4GWs.

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.

Manuscript received April 5, 2007
Manuscript revised April 25, 2007

This paper is organized in the following way: Section 1 introduces the paper. Section 2 presents different perspectives of the 4G design. The most probable design and capabilities of the 4G are presented in Section 3. The following sections describe the definition of 4G as a significant factor influencing wireless networks. Section 4 details how 4G technology might influence networks. Section 5 highlights implementation issues of 4G in the mobile military environment by introducing 4GM@4GW terminology. Finally, Section 7 concludes and describes future work.

2. Many Faces of 4G

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 forth generation of mobile wireless networks (4GM) can be implemented in the modern military environment known as the forth 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

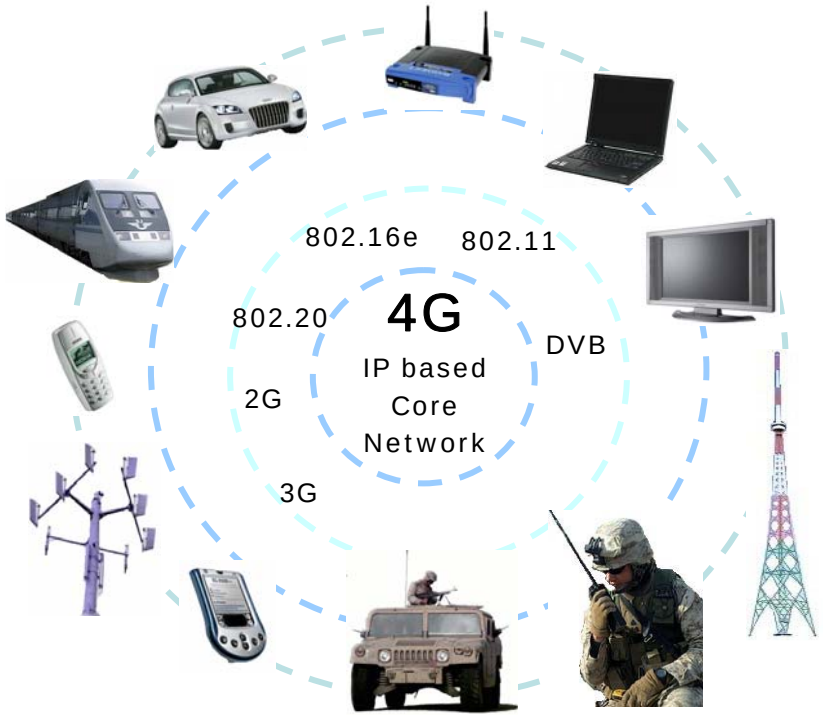

Fig. 1 Many faces of 4G

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.

The general concepts of 4G can be present 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

3. 4G – The Final Definition

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.

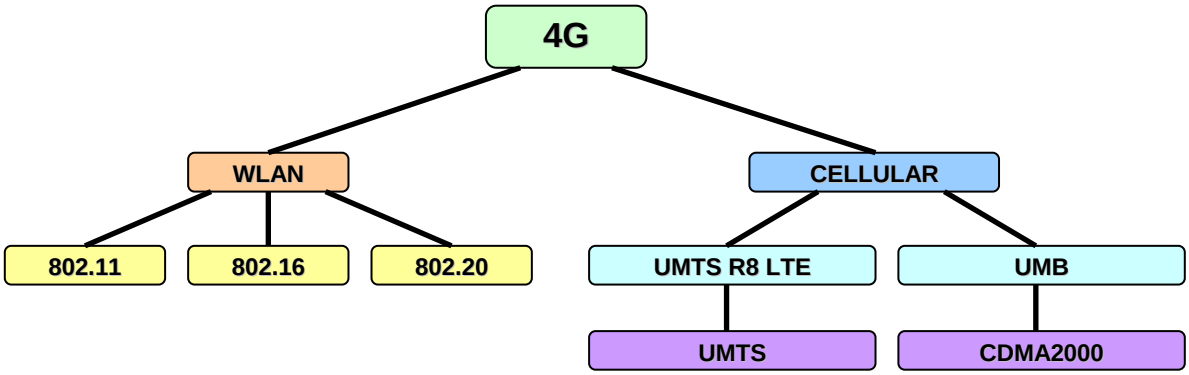

Fig. 2 Evolution of 4G

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].

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].

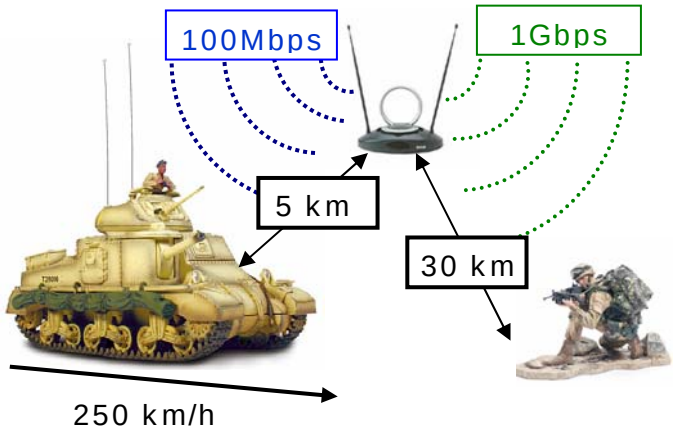

Fig. 3 4G mobility, bandwidth and range in military environment

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.

4. 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.

4.1 MIMO

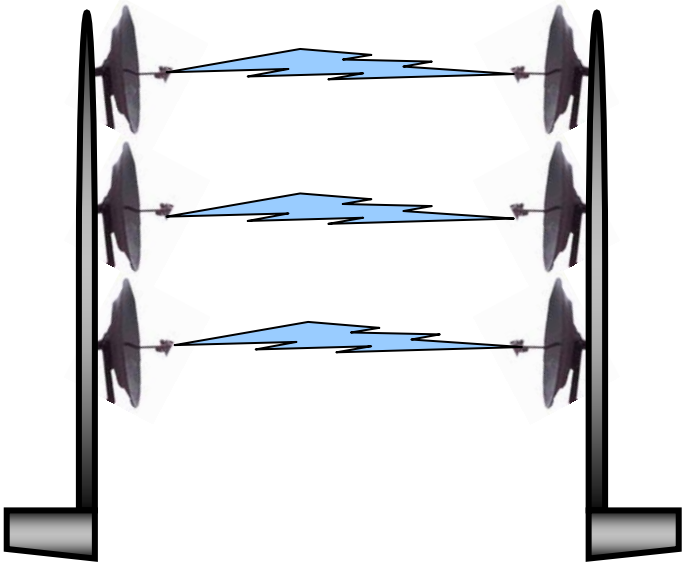

Fig. 4 MIMO spatial multiplexing

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.

4.2 OFDMA Evolution

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].

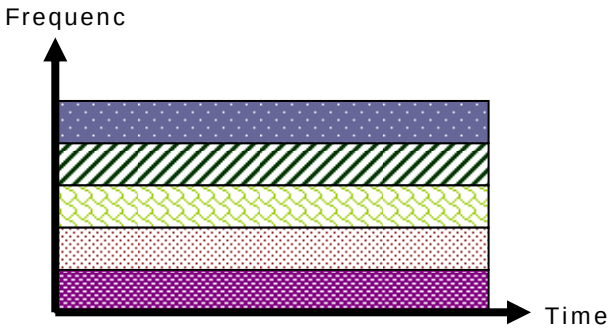

Fig. 5 FDMA

Before OFDM become popular, three other solutions were presented to share radio spectrum between multiple users. Used by 1G, FDMA (Frequency Division Multiple Access, Fig. 5) partitioned channel between users. To increase channel capacity, TDMA (Time Division Multiple Access, Fig. 6) was proposed that allocate each user access to the whole bandwidth for short period of time.

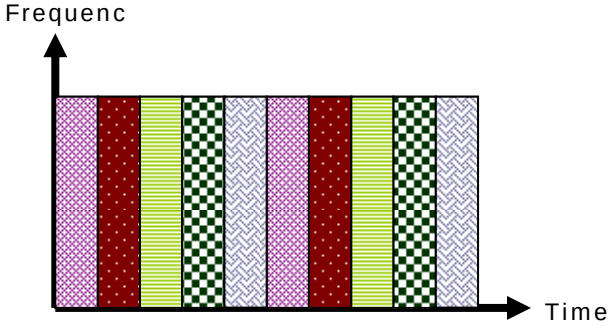

Fig. 6 TDMA

Because TDMA in 2G caused interference problem, CDMA (Code Division Multiple Access) was proposed as a new form of multiplexing where each user was allowed to use the whole channel capacity all the time. Different messages were transmitted with associated special code which was later used to distinguish between them.

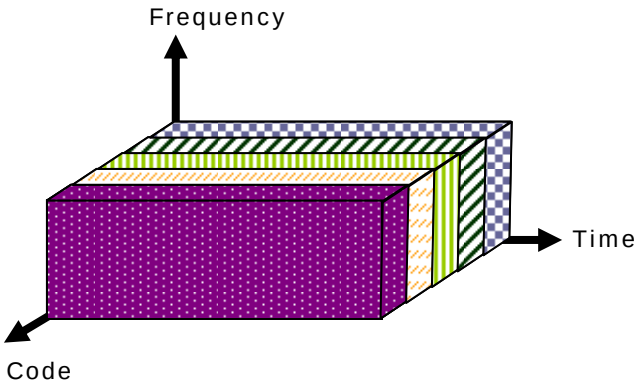

Fig. 7 CDMA

The better data throughput become possible, when using orthogonal frequency division multiplexing, the radio bandwidth could be subdivided into narrowbands.

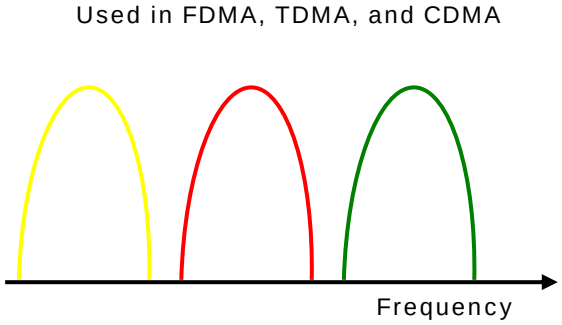

Fig. 8 Sharing frequency in FDMA, TDMA, and CDMA

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

The simplest method of sharing performance achieved by OFDM is distribution using TDMA known as OFDM-TDMA [24]. OFDM-TDMA can be represented by Figure 6, considering that frequency channels are orthogonally subdivided as in Figure 9.

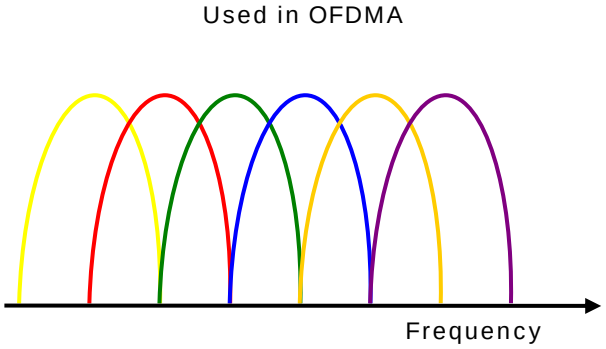

Fig. 9 Sharing frequency in OFDMA

4.2 HIP

Enhanced mobility in broadband wireless access is the key concept of the 4G. New frequency division methods as well as single interfaces for cellular and wireless networks are not enough to support constant nodes' mobility between networks because of limitations of the internet protocol in the network layer. Every host in a network is identified by IP address that needs to be changed whenever a node leaves one network and move to another one.

Fig. 11. When moving from one network to another, host id stays same and IP address changes.

To simplify nodes mobility, HIP (Host Identity Protocol) was proposed that would introduce additional Host ID layer between transport and network layer to the internet protocol stack (Figure 10) and enable continuity of

communication by establishing connections with host ids, but not with host locations. Host identifiers are 128-bit public keys, called Host Identity Tags (HIT), for which hash function is applied [29][30].

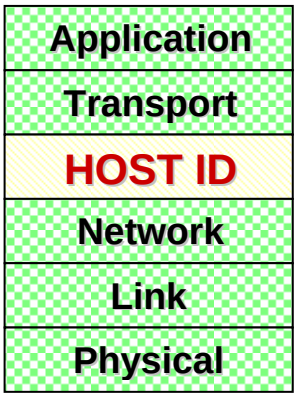

Fig. 10. New Host ID layer will simplify nodes' mobility in 4G.

HIP will not only enable end-host mobility, but will also simplify multi-address multi-homing with integrated security over IPv4 and IPv6 [30]. Although the multi-homing features are already available through SCTP (Stream Control Transmission Protocol) that was designed to provide better transmission service for multimedia applications such as video-streaming and VOIP and supports packet delivery using multiple streams [31], none of the popular internet application are using SCTP yet because of its complication in use. The end-point identifiers called host IDs are public keys. Whenever a client request a connection with a host address, DNS returns a Host ID, that later is translated to an IP address. Thus end-point identifiers are controlled by Host ID layer, and host location is controlled and properly updated by the network layer [30]. Finally, HIP has another benefit of its resistance to CPU and memory Denial-of-Service attacks as well as the Man-in-the-Middle attack. Encapsulated Security Payload and available encryption for TCP and UDP also signifies the security importance of HIP [32]. The HIP project of IETF will be scheduled to be finished by end of 2007.

5. 4G MANET in Military Environment

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 fist explain the 4GW term defined by William Lind, an American expert on military affairs, as the theory of the Forth Generation War.

6.1 4GW

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."

6.2 4GM@4GW Constraints

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.

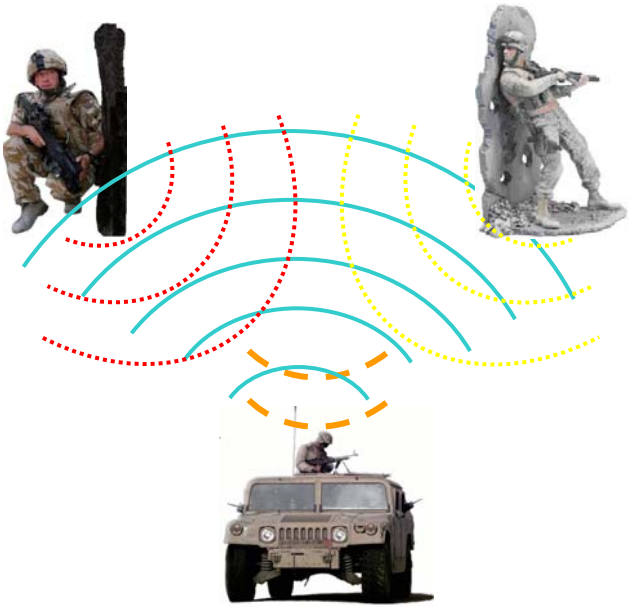

Fig. 12 Hidden terminal problem: soldiers signal are prevented from hearing each other. The signal to the destination car is interfered.

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.

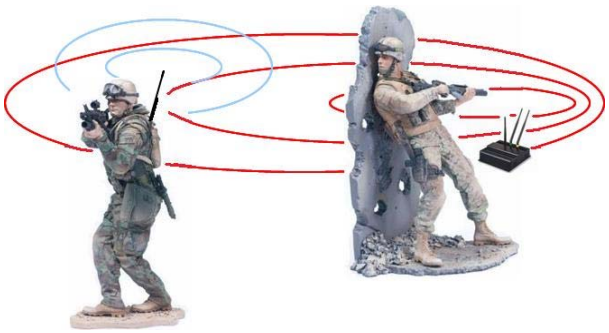

Fig. 13 Enemy forces use jammer to interfere army's signal.

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 (Figure 12) 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 (Figure 13). In many cases, successful DoS can be more important that decrypting information

because of its immediate influence on the army's condition.

6. Conclusion and future work

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, the 4GM@4GW, 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 issues considered by 4GM@4GW. 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 be penetrated 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.

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.

References

[1] IETF. "Mobile Ad-hoc Networks (MANET)." The Internet Engineering Task Force, http://www.ietf.org/html.charters/manet-charter.html
[2] Perkins C., Belding-Royer E., Das S., "Ad hoc On-Demand Distance Vector (AODV) Routing." Network Working Group Request for Comments: 3561. http://www.ietf.org/rfc/rfc3561.txt
[3] Clausen T., Jacquet P., "Optimized Link State Routing Protocol (OLSR)." Network Working Group Request for Comments: 3626. http://www.ietf.org/rfc/rfc3626.txt
[4] Kurose J., Ross K., "Wireless Links and Network Characteristics." Computer Networking pg. 508-513. Pearson Education, Inc.
[5] Woerner B., Howlader M., "Research Directions for Fourth Generation Wireless." http://csdl.computer.org/comp/proceedings/wetice/2001/1269/00/12690060.pdf
[6] Hussian S., Hamid Z., and Khattak N., " Mobility Management Challenges and Issues in 4G Heterogeneous Networks." http://portal.acm.org/ft_gateway.cfm?id=1142698&type=pdf&coll=&dl=acm&CFID=15151515&CFTOKEN=6184618
[7] Delson Group Inc., "Open Wireless Architecture." http://delson.org/cwc/owa.htm
[8] Ibrahim J., "4G Features". Bechtel Telecommunication Technical Journal. (December 2002):11-14 http://www.bechteltelecoms.com/docs/bttj_v1/Vol1No1.pdf
[9] Steer M., "Beyond 3G." IEEE Microwave Magazine. No.1 (February 2007). http://people.engr.ncsu.edu/mbs/Publications/vitae_papers/2007/steer_magazine_feb_2007.pdf
[10] 3GPP. http://www.3gpp.org/
[11] 3GPP2. http://www.3gpp2.org/
[12] Boppana D., Batada A., "How to create beam-forming smart antennas using FPGAS." Embedded.com. http://www.embedded.com/showArticle.jhtml?articleID=60401726
[13] Wimax Forum, "Technology." http://www.wimaxforum.org
[14] The IEEE 802.16 Working Group on Broadband Wireless Access Standards, "General Information." http://www.ieee802.org/16/
[15] Datacomm Research Company , "Using MIMO-OFDM Technology to Boost Wireless LAN Performance Today." http://www.datacommresearch.com/whitepapers/Downloads/MIMO-OFDM_for_Wireless_LANs_White_Paper_1.0.pdf
[16] Dhillon G., "Why MIMO makes sense for next-generation cellular." Wireless Net Design Line. http://www.wirelessnetdesignline.com/howto/wlan/showArticle.jhtml?articleId=185300393&pgno=3
[17] TTA, "WiBro Overview." WiBro. http://www.wibro.or.kr

[18] The IEEE 802.16e Task Group (Mobile WirelessMAN), "Official Documents." http://www.ieee802.org/16/tge/
[19] The IEEE 802.20 Mobile Broadband Wireless Access (MBWA). http://grouper.ieee.org/groups/802/20/
[20] DVB Project, "What is the DVB Project?" http://www.dvb.org/
[21] Bauer J., Lin Y., Maitland C., Tarnacha A., "Transition Paths to Next-Generation Wireless Services." 32nd Research Conference on Communication, Information and Internet Policy. http://quello.msu.edu/wp/wp-04-04.pdf
[22] "Ericsson Demos Live LTE at 144Mbps", ABI Research Wireless Daily Newsletter, February 09, 2007
[23] Top Global USA. "Recent News Release." http://www.topglobalusa.com/press.asp
[24] Lawrey E., "Adaptive Techniques for Multiuser OFDM." James Cook University. http://www.skydsp.com/resources/OFDM_thesis_lawrey.PDF
[25] Datacomm Research Company. "Using MIMO-OFDM Technology to Boost Wireless LAN Performance Today." http://www.datacommresearch.com/whitepapers/Downloads/MIMO-OFDM_for_Wireless_LANs_White_Paper_1.0.pdf
[26] Lind W., Schmitt J., Wilson G., "The Changing Face of War: Into the Fourth Generation." Marine Corps Gazette. (October 1989): pg. 22-26. http://www.di.net/fcs/4th_gen_war_gazette.htm
[27] Defense and the National Interest. "Fourth Generation Warfare." Kettle Creek Corporation. (January 1, 2007). http://www.d-i.net/second_level/fourth_generation_warfare.htm
[28] Hammes T., "The Evolution of War: The Fourth Generation." Marine Corps Gazette. http://www.d-n-i.net/fcs/hammes.htm
[29] InfraHIP Project. "How HIP Works" http://www.infrahip.net/
[30] Host Identity Protocol (hip) Charter. "Host Identity Protocol." IETF. http://www.ietf.org/html.charters/hip-charter.html
[31] Stevens R., Fenner B., Rudoff A. (2004) "Unix Network Programming." Boston: Addison-Wesley.
[32] Moskovitz R., Nikander P., Jokela P., Henderson T. "Host Identity Protocol draft-ietf-hip-base-07." Network Working Group Internet-Draft. (February 1, 2007). http://www.ietf.org/internet-drafts/draft-ietf-hip-base-07.txt

Marcin Szczodrak is a student in the Department of Mathematics and Computer Science, John Jay College of Criminal Justice (The City University of New York), New York, NY 10019 USA.

Dr. Jinwoo Kim is an Assistant Professor at the Mathematics and Computer Science Department, John Jay College of Criminal Justice (The City University of New York), New York, NY 10019 USA. (He is also a faculty member of the CUNY Graduate Center's Computer Science Ph.D Program and John Jay College's Graduate Program in Forensic Computing and a staff of the Center for Cyber Crime Studies at John Jay College of Criminal Justice.)

Dr. Yuncheol Baek is an Associate Professor at the Division of Computer Software, Sangmyung University, Seoul, Korea. (He is currently a research fellow at the Department of Electrical Engineering, Princeton University, Princeton, USA.)