Toward Future Innovation of Mobile Communication Systems – Current Requirements for Research –

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ABSTRACT

Broadband wireless communication and 3G cellular phones are becoming popular and several multimedia and location aware services are being available. In this paper, we summarize the current situation of mobile communication systems, and watch their future trend. Some research requirements for their future innovation are discussed. Our efforts for the design and realistic performance evaluation of MANET applications are also introduced.

Keywords: mobile communication, MANET applications, 3G cellular phones, future perspective

1 Introduction

Due to the progress of the Internet and cellular phones, mobile communication systems are becoming popular. New services on 3G cellular networks have started in some countries. For example, in Japan we can access to the Internet from PCs and PDAs at any place through 3G cellular networks whose data transmission speed is a few hundred Kbps up to a few Mbps. The cellular phone carriers offer a lot of multimedia and location aware services such as download services of music, games, novels and videos [1]. In Asian countries, personal navigation services such as EZNaviWalk, igogo, NaviStar and Navi by Hutch are also available where a shortest route to a given destination is calculated and the user is navigated with the route on a graphical map. On the other hand, we can use broadband infrastructures such as ADSL and FTTH from our home with rather cheap costs (e.g. 30-50$/month). In large cities, we can also find several wireless LAN spots which provide broadband wireless communication services. Seamless integration of these cellular networks and broadband wireless LANs may become popular soon for ubiquitous access services, although it is not available now. Ubiquitous society using broadband mobile communication is just around the corner. However, in order to make affluent ubiquitous society, further innovation of mobile communication systems is still needed.

Many policies are considered to encourage technological innovation of mobile communication. In USA, NSTC (National Science and Technology Counsel) organizes NITRD (Networking and Information Technology Research and Development) program where sensor networks are eagerly studied and many accomplishments concerning with defense and homeland security are achieved. Research on the incorporation of micro sensors into wireless networks for environmental monitoring is also studied. On the other hand, the spread of 3G cellular phones may still take time. In EU, 3G cellular phones have just started to spread and Sixth Framework Programme (FP6, 2003-2006) is carried out where mobile and wireless systems and platforms beyond 3G are studied. Here, harmony of various network infrastructures such as cellular networks and wireless LANs is considered. In contrast to USA and EU, 3G cellular phones have come into wide use recently in Asian countries, especially in Japan and Korea. Many people use cellular phones to access to the Internet, mainly to exchange e-mails and access to WWW. In these countries, some policies for deployment of high speed communication infrastructures are also provided. For example, e-Japan strategy was adopted in Japan for the spread of such high speed communication infrastructures. This policy is extended to u-Japan strategy where construction of ubiquitous networks using mobile communication is considered.

Various services are already provided to 3G cellular phones, which include multimedia communication services such as on-demand video playback and video telephony, and location aware services such as information diffusion and retrieval. In the future ubiquitous society, these services are expected to be provided with higher quality, as available transmission speed becomes higher in the next generation cellular networks. Since it takes time to construct 4G generation cellular network infrastructure everywhere, wireless LAN technology will be complementarily used with the cellular phone networks, especially for local area communication required for ubiquitous services. In order to construct ubiquitous network environments, mobile ad-hoc networks (MANETs) become key components where autonomous connections among mobile nodes are formed without fixed network infrastructures and centralized administrations [2], [3]. In order to design and implement mobile communication systems in such environments, we must consider various unsolved issues such as design and functionality of cellular phones, energy consumption and security. In order to achieve efficient communication in such hybrid wireless networks, computer simulation for large scale networks is essential.

In the rest of the paper, we summarize the current situation of mobile communication systems in Section 2, and watch their future trend in Section 3. Some research requirements for their future innovation are also listed. Our efforts for the design and realistic performance evaluation of wireless network applications are introduced in Section 4.

Generation	Comm. Speed and Type	System Standard	MAC	Years
1G	2.4Kbps (voice only)	(analog)	FDMA	1980s
2G	9.6K – 28.8Kbps	GSM, PDC, cdmaOne	TDMA, CDMA	1990s
2.5G	56K – 384Kbps	GPRS, EDGE	TDMA	late 1990s–2000
3G	384K–2.4Mbps	IMT-2000 (ex. W-CDMA, CDMA2000)	CDMA	2000s
Super 3G	30M-100Mbps	Agree to standardize (2007.6)	CDMA	late 2000s
4G	100Mbps			after 2010

Table 1: Overview of Cellular Network Generations

2 Mobile Wireless Communication at Present

In these days, the most popular mobile wireless communication in wide area is done by cellular networks. Firstly, we overview the current deployment of cellular networks in the world. Then we observe the deployment of wireless LAN services in public space, which provide the highest speed mobile broadband access to the Internet at present in local regions.

Starting from analog phones in the first generation in 1980s, digital phones have become available in the second generation since 1990s. In the second generation, GSM becomes a standard system and is wide-spread to many countries in North America, Europe and so on. Since the late of 1990s, the generation called 2.5G, where data communication speed is enhanced from 2G, has become available, and nowadays several countries are shifting to the third generation based on the CDMA technologies. Table 1 summarizes these cellular generations [1].

We can see the outstanding mobile phone Internet subscriber rates in the countries of Asian region as shown in Table 2. This is deeply related with the deployment of 3G mobile phones. Table 2 indicates that about 90% of mobile phone subscribers are the mobile phone Internet subscribers in Japan. Also 3G mobile phones account for more than 30% of all the mobile phones (Table 3). In Japan, people like to exchange pictures on the mobile phones through the cellular networks and the Internet. Also new multimedia services such as high quality music download require much more bandwidth. These reasons may attract users to 3G cellular phones.

Wireless LAN services in public space are also important for mobile broadband communication. In many countries, spots are located in public space such as hotels, airports, coffee-houses and stores. IEEE802.11 using the ISM band is the most popular and well-known international standard. In Japan, there were 1,620 spots in March 2003. Then in March 2004, just one year later, the number became 5,350. This indicates that we will experience extensive growth of wireless LAN public service users in near future.

3 Future Trends and Directions in Mobile Communication Systems

As transmission speed increases in wireless communication, we expect that service applications through mobile wireless networks will become more popular in the world. As we have already seen in Table 3, approximately 28 million people in Japan (32% of all cellular phone users) are now using 3G cellular phones. Various services are already available to 3G cellular phone terminals. These services include pedestrian navigation services using GPS [4], download/playback of CD quality music files, on-demand video playback, and video telephony. These services will be enhanced, using richer contents such as higher quality maps, musics and videos as capabilities of mobile phones become more powerful. This will bring demands for higher transmission speed mobile communication.

Country	%	Country	%
Japan	89.5	Switzerland	13.2
Republic of Korea	87.0	France	12.5
China	30.9	USA	12.1
Singapore	25.3	New Zealand	12.0
Taiwan	24.4	Portugal	11.1
Italy	22.4	United Kingdom	9.3
Canada	21.7	Hong Kong	8.7
Austria	20.2	Germany	8.5
The Netherlands	19.3	Spain	8.3
Finland	17.9	Belgium	1.2
Australia	14.8	Denmark	1.1

Table 2: Mobile Internet Subscribers of All Mobile Phone Subscribers (End of Sept. 2003)

Even though the next generation mobile phones provide up to 100Mbps communication speed, it might not be able to cover all the areas by the new generation infrastructure, since considerable cost is required to build infrastructures everywhere for the high speed WANs. Hence in the next generation, wireless LANs will be complementarily used with existing CDMA/PDC/GSM networks, and they will be seamlessly connected to these networks to enlarge broadband communication areas. Also, wireless LANs have a great potential to enlarge its communication area in node-by-node basis, *i.e.* in a multi-hop manner. Some mobile phone products with wireless LAN communication capability are already on the retail market.

Let us assume that mobile phones are equipped with wireless LAN devices. They may form mobile ad hoc networks using the wireless LAN devices, and some of them connect to the Internet via wireless LAN access points or routers. Some local services or communication among users within a local region might be covered only by ad-hoc communication on a multi-hop wireless LAN. For not only local area communications and services but also wide area communications and services, the mobile ad-hoc network will be complementarily used to diffuse shared information obtained from the Internet to multiple nearby nodes, to

	Mar. 02	Sep. 02	Mar. 03	Sep. 03	Mar. 04	Sep. 04	Feb. 05
CDMA2000 (3G)	–	2,652	6,805	10,203	13,509	15,858	17,393
W-CDMA (3G)	89	136	355	1,086	3,183	6,749	10,918
Total (All Generations)	69,349	72,331	75,944	78,933	81,921	84,312	86,142
3G Ratio	0.1%	3.9%	9.4%	14.3%	20.4%	26.8%	32.9%

Table 3: Number of Mobile Phone Subscribers (K/unit) in Japan. (From Telecommunication Carriers Association (TCA) web site http://www.tca.or.jp/)

provide those nodes several potential routes to the Internet and so on.

In this perspective, we expect that the following types of new applications will emerge for next generation mobile phones; (i) localized real-time communication among cellular phone users, and (ii) localized information service. Applications falling into type (i) may include, for example, real-time video/audio communication between two nodes in a local region, through ad-hoc networks or other localized networks. Although these kinds of applications are already available through cellular networks, such an application through ad-hoc networks will be useful for emergency service (e.g., rescue activities when infrastructure is damaged) and/or providing services at cheaper cost to users (e.g., seeing video of road conditions far away via inter-vehicle communication). Applications in type (ii) may include retrieval and distribution of advertisements of shops and events from/to nearby users. If a user specifies preference (e.g., keywords) on his/her cellular phone, the user can receive ads (e.g., on sale, happy hour, and so on) matching his/her preference.

In order to realize these kinds of applications, we have to solve a lot of problems. For example, design of cellular phone terminals should be more functional, in order to allow users to easily see information and/or input data while walking, and so on. Recently, mobile phone terminals integrate many different wireless communication devices, and this makes the terminals big, costly and energy consuming. To cope with this problem, software radio technology [5] might be adopted. In order to access various types of applications, security mechanisms should be carefully considered. Non-contact IC cards such as FeliCa [6] are integrated into some of cellular phones to allow users to pay for something (e.g., tickets) through the terminals. For this purpose, some mobile phones adopt bio-metric authentication mechanisms. While packets are transmitted through cellular networks, security for communication is rather easy to achieve, since carriers can monitor and control all nodes in their networks. However, if services are provided through mobile ad-hoc networks, malicious nodes can easily disturb services or conduct attacks to nodes on the paths between the service providers and users.

There are several types of attacks in ad-hoc networks [7]. The packet misordering attack, packet dropping attack, and delay-variance attacks are attacks using characteristics of TCP congestion control, and give significant damage in packet delivery throughput. The black hole attack is the attack in which malicious nodes on packet delivery paths receive packets and do not forward them. In [8], a new type of attack called the wormhole attack which completely damages most ad-hoc routing protocols

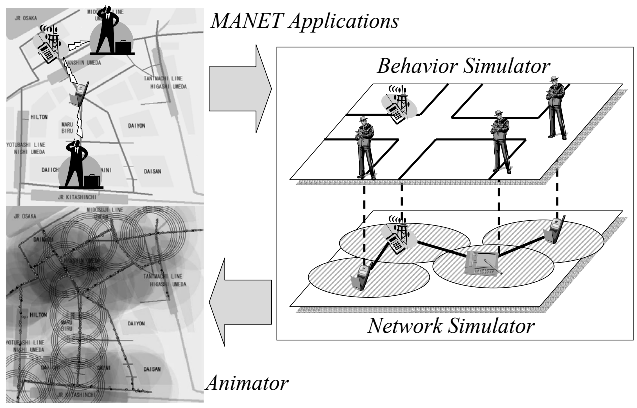


Figure 1: MobiREAL Simulator.

is identified and its detection mechanism is proposed. As mobile ad-hoc networks become popular, many more malicious attacks will emerge. So, we definitely need techniques to completely detect and dissolve these attacks from ad-hoc networks.

The last and big problem is how to design, develop and evaluate the above types of ad-hoc network applications. There are many simulators to evaluate the performance of ad-hoc network protocols. However, they only support simple node mobility such as random walk in a free space.

In the following section, we present our approach to make those applications deployable in the real world, mainly in the performance evaluation aspect.

4 Toward Future Innovation – Our Approach

Toward future mobile communication systems, we present two approaches in this paper. One is to develop a “real” mobile network simulator called MobiREAL which allows application developers to evaluate mobile applications in more realistic environments. The other is to realize inter-vehicle communication as well as to develop a network simulator which works together with a realistic traffic simulator.

4.1 MobiREAL Simulator and Performance Evaluation of MANET Application

As discussed in the previous section, Mobile Ad-hoc Networks (MANETs) are expected to be very useful and important infrastructure for achieving future ubiquitous society. Designing MANET protocols and applications is a very complicated task since it is hardly possible to build large-scale and realistic testbeds in real world for performance evaluation. Thus there are always demands for the testbeds which allow us to design, analyze, and validate the applications in simple and inexpensive ways. Nowadays network simulators are mainly used for such a purpose.

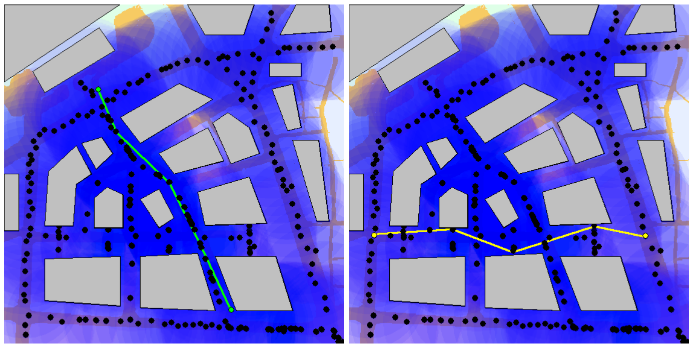
We usually use simple mobility models such as the Random Way Point (RWP) model [9] without any obstacles, for simulating MANET protocols, because such simple mobility models can commonly be utilized in many simulators. This means that researchers can share the same testbeds for comparing performance of various protocols. However, if we want to accurately evaluate performance of higher layer MANET protocols or applications, we should carefully choose mobility models that can generate realistic topology and node behavior likely to appear in real environments.

A simple but typical example is a location-aware application that diffuses information (*e.g.* information about road congestion ahead), from person to person, to people who are going to pass the congested region, in order to allow them to change their routes. If we use RWP model for evaluating such an application, we never see, for example, how the congested region dynamically changes or disappears while some people change their routes by receiving the congestion information from the diffusion application. We need a computational behavior model of mobile nodes which is simple, but has enough expressive power to model such realistic mobility.

We propose a new method to model and simulate realistic mobility of nodes. In the method, we adopt a probabilistic rule-based model called *Condition-Probability Event Model* (*CPE Model*) to describe behavior of mobile nodes. In our model, mobile nodes are classified into multiple groups depending on their behavior patterns. We assume that one CPE model is given to each group of mobile nodes. At a specified time period, new positions, directions and velocities of the mobile nodes are recalculated according to the pre-defined rules with probabilities. Based on the proposed methodology, we have developed a network simulator called *MobiREAL*[10] (see Fig. 1). Our MobiREAL simulator can simulate any protocols and applications on mobile ad-hoc networks composed of mobile nodes with realistic movements. This can be achieved by cooperation of two main components of the MobiREAL simulator, which undertake mobile nodes' behavior simulation and MANET network simulation, respectively. The MobiREAL simulator can record the trace files during the simulation and with the trace file, our MobiREAL animator can elegantly display, for example, how links are established and how information is diffused among mobile nodes.

As an example MANET application that needs realistic performance evaluation, we consider end-to-end real-time communication on MANETs. Here, if a route is established along the street, the route might be more stable than that established vertically to the street, since in the former case the mobile nodes may move to the same direction. This is an interesting example to see how mobility models affect the performance. For such a purpose, we have modeled a real 500m$\times$500m region in the downtown of Osaka city (see Fig. 2).

We have simulated two cases A and B. In the scenario of case A, two application users (they never move) try to establish an UDP connection along a main street (they stay at the ends of the street). In the scenario of case B, they also never move, but there are several streets between them. We use the two types of mobile nodes (shopping customers and workers). In both scenarios, the physical distances between the application users are the same. Usually, workers move between landmarks (buildings and stations). In the simulation region of the downtown, we have a big landmark in the north area, the central station. We also have some big buildings in the south area and big streets connecting the north and south areas. Since we have set the destinations of those workers according to the scale of the landmarks, as a total, some major convective flows of mobile nodes were formed in the north-south direction in the both scenarios. For the shopping customers, we have set major landmarks as their destinations. The ratios of the workers and the shopping customers are 0.8 and 0.2 (we assume these values based on our observation), respectively. The simulation time was 720 seconds. The application was executed from time 240 sec. to time 720 sec. The initial velocity of mobile nodes is 2 m/s, and the average density of the nodes is 0.00048 person/m^2. The animator snapshots of the both cases are shown in Fig.2.



(a) case A (b) case B

Figure 2: Snapshots of two simulation scenarios.

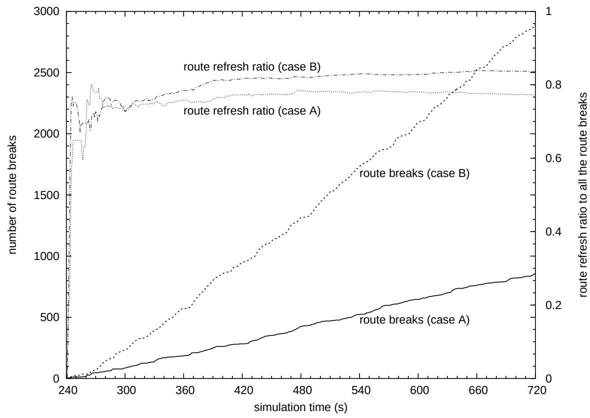


Figure 3: Simulation time vs. the accumulative number of route breaks. The accumulative ratio of the number of local recoveries to the number of route breaks is also shown using the right-hand-side Y-axis.

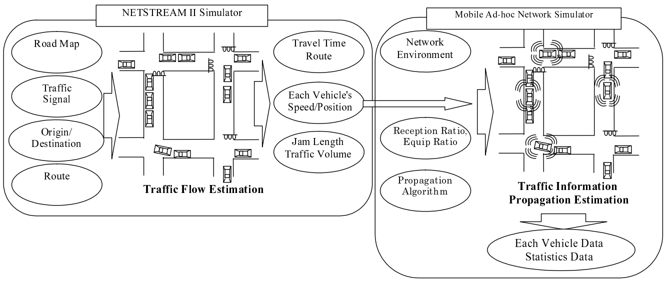


Figure 4: Mobile Ad-hoc Network Simulator for Evaluation of Inter-vehicle Communication

DSR is used as the routing protocol, and after the connection is established, 10Kbps traffic is generated interactively between the two users to simulate interactive real-time communication. We have used IEEE 802.11 (CSMA/CD with RTS/CTS). The radio range is 100 meters.

Fig. 3 shows the accumulative number of route breaks (we also show the ratio of the number of local recoveries to the number of route breaks) during the simulation time frame (from time 240 sec. to 720 sec.). We can clearly see that case B has much larger numbers of route breaks, compared with case A. This validates the fidelity of modeling of mobile node behaviors as well as convinces us of the demands for realistic mobility in simulations of MANET applications.

4.2 Inter-Vehicle Ad-Hoc Communication and Its Performance Evaluation

We take up another type of mobile ad-hoc communication, and introduce a method for its realistic evaluation. Recently, the research to propagate and acquire traffic jam information using inter-vehicle communication is actively studied[11], [12]. To build inter-vehicle ad-hoc networks without base stations, some data dissemination methods have been proposed[13], [14]. However, they do not consider realistic environments such as traffic jams and signal waiting. In addition, most of them assume collision free communication so that all the data can be received successfully. In actual traffic jam conditions, broadcasting data from many vehicles may cause a broadcast storm [15], and too many collisions may prevent the inter-vehicle communication. So, we should take care to prevent the collisions. Evaluation based on realistic traffic models will make more realistic dissemination protocols. Here, we will explain a method for this purpose.

NETSTREAM [16] is a traffic flow simulator for performing the effective prediction for traffic jams and prior evaluation of ITS introduction. It defines traffic flow characteristics and the lengths of signals for all road links, and then calculates all vehicles actions for every second. Therefore in wide areas such as a large city, it can calculate the traffic flow with high accuracy. To evaluate traffic information propagation situations in an inter-vehicle ad-hoc network setting, we have developed a network simulator. As shown in Fig. 4, our mobile ad-hoc network simulator cooperates with NETSTREAM so that we can evaluate our inter-vehicle communication protocol with typical traffic flow. Our network simulator also considers packet collisions for more realistic simulation.

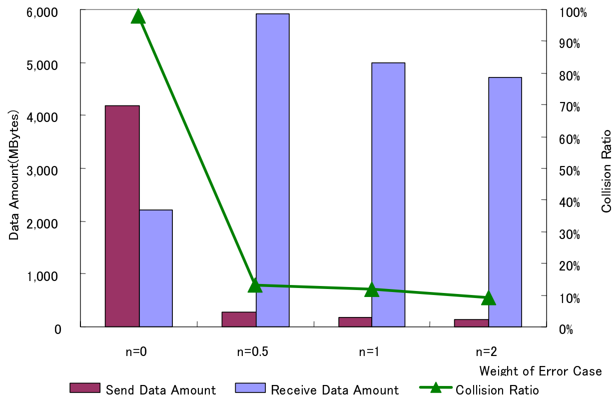


Figure 5: Collision Ratios for Various Weighted Numbers n

We have proposed a protocol called RMDP (Received Message Dependent Protocol) [17], [18]. In RMDP, we assume that the dissemination interval is in inverse proportion to the numbers of reception messages and reception errors. Here, we propose a method for obtaining the parameters to maximize the total amount of the reception data using our simulation results. Let $\gamma = M_{success} + M_{error} * n$ denote a weighted number of reception messages and reception errors where $M_{success}$ and M_{error} denote the number of successful reception packets and that of the detected reception errors, respectively, for the last 30 seconds, and n denotes a non-negative constant representing the weighted number. Then, we define the dissemination interval P in a fixed period (30 seconds) as $P = \frac{\alpha}{1-\beta\gamma}$ $(\alpha, \beta > 0)$. In our simulation, we have used a road map whose size is 20km* 20km where the number of signals is 198 and the number of vehicles is 4890. We have simulated for 60 minutes. From our simulation results, we obtained 0.14, 0.06 and 0.5 as suitable values of α, β and n, respectively. So we can estimate the suitable dissemination interval P when the numbers of reception messages and reception errors for 30 seconds are given.

We have made a traffic jam from an intersection whose length is about $700m$, and evaluated how much time each vehicle need to acquiring the information of traffic jam head when the vehicle has just reached the tail of the traffic jam. We have also measured the collision ratios for various weighted numbers n. Fig. 5 shows the collision ratios. If we do not consider packet collision errors (that is, if n is 0), more than 90% of packets have a collision with each other. From our experiments, we have recognized that 0.5 is suitable as the weighted number n. The time necessary for acquiring the information of traffic jam head strongly depends on the weighted number n. If we assign 0.5 as the weighted number n, more than 98% of vehicles can acquire the traffic jam heads information in a few seconds. If we give 0 and 2 as n, only less than 90% of vehicles can obtain the information because of inadequate treatment of packet reception errors. Thus, adequate dissemination protocols considering re-

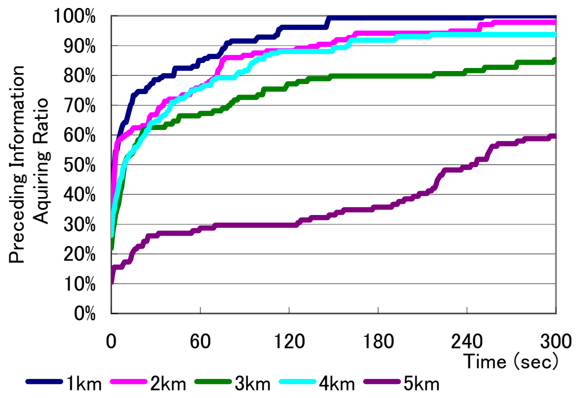


Figure 6: Time Necessary for Acquiring Preceding Road Information

alistic traffic conditions are needed for designing efficient inter-vehicle communication, Fig. 6 shows the time necessary for acquiring preceding road information when we use the proposed RMDP protocol. From this figure, more than 80% of vehicles can obtain the road information of 1km ahead from the current position in 30 seconds.

By designing a fully worked-out protocol, efficient acquisition of preceding road information becomes possible. For this purpose, the use of accurate traffic models (mobility models) is essential.

5 Conclusion

Recently, 3G cellular phones become popular where high speed mobile communication becomes available. This makes several multimedia and location aware services possible. In the next generation, wireless LANs will be complementarily used with existing cellular networks, and seamless communication among mobile nodes will be possible. Mobile ad-hoc communication becomes a key technology in such environments although we need more realistic mobility models and evaluation tools. In this paper, we give our perspective and efforts for future innovation of mobile communication. We hope research related to mobile communication becomes more active in order for making affluent ubiquitous society.

REFERENCES

[1] Ministry of Public Management, Home Affairs, Posts and Telecommunications, Japan. *Information and Communications in Japan*, 2004. White Paper.

[2] C.-K. Toh. *Ad Hoc Mobile Wireless Networks - Protocols and Systems -*. Pearson Education, 2002.

[3] S. Basagni, M. Conti, S. Giordano, and I. Stojmenovic. *Mobile Ad Hoc Networking*. IEEE Press, 2004.

[4] Qualcomm. Qualcomm CDMA technologies – gpsOne A – GPS solutions for CDMA. `http://www.cdmatech.com/solutions/products/gpsone_cdma.jsp`.

[5] W.H.W. Tuttlebee. *Software Defined Radio : Baseband Technologies for 3G Handsets and Basestations*. Wiley, 2004.

[6] Sony. Felica. `http://www.sony.net/Products/felica/`.

[7] I. Aad, J.-P. Hubaux, and E. W. Knightlyz. Denial of service resilience in ad hoc networks. In *Proc. of ACM/IEEE Mobicom*, 2004.

[8] Y.-C. Hu, A. Perrig, and D. B. Johnson. Packet leashes: A defense against wormhole attacks in wireless networks. In *Proc. of IEEE Infocom*, 2003.

[9] J. Broch, D.A. Maltz, D.B. Johnson, Y.-C. Hu, and J. Jetcheva. A performance comparison of multi-hop wireless ad hoc network routing protocols. In *Proc. of ACM/IEEE Mobicom*, pages 85–97, 1998.

[10] MobiREAL web page. `http://www.mobireal.net`.

[11] H. Hartenstein, B. Bochow, A. Ebner, M. Lott, M. Radimirsch, and D. Vollmer. Position-aware ad-hoc wireless networks for inter-vehicle communications: the Fleetnet project. In *Proc. of ACM Mobihoc*, pages 259–262, 2001.

[12] M. Papadopouli and H. Schulzrinne. Effects of power conservation, wireless coverage and cooperation on data dissemination among mobile devices. In *Proc. of ACM Mobihoc*, pages 117–127, 2001.

[13] A. Khelil, C. Becker, J. Tian, and K. Rothermel. An epidemic model for information diffusion in MANETs. In *Proc. of 5th ACM Int. Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems (MSWiM'02)*, pages 54–60, 2002.

[14] B. Xu, A. Ouksel, and O. Wolfson. Opportunistic resource exchange in inter-vehicle ad-hoc networks. In *Proc. of 2004 IEEE Int. Conf. on Mobile Data Management (MDM2004)*, pages 4–12, 2004.

[15] S. Ni, Y. Tseng, Y. Chen, and J. Sheu. The broadcast storm problem in a mobile ad-hoc network. In *Proc. of ACM/IEEE Mobicom*, pages 151–162, 1999.

[16] E. Teramoto, M. Baba, H. Mori, H. Kitaoka, I. Tanahashi, and Y. Nishimura et. al. Prediction of traffic conditions for the nagano olympic winter games using traffic simulator : NETSTREAM. In *Proc. of 5th World Congress on Intelligent Transport Systems*, pages 1801–1806, 1998.

[17] M. Saito, J. Tsukamoto, T. Umedu, and T. Higashino. Evaluation of inter-vehicle ad-hoc communication protocol. In *Proc. of 19th Int. Conf. on Advanced Information Networking and Applications (AINA2005)*, 2005. (to appear).

[18] M. Saito, M. Funai, T. Umedu, and T. Higashino. Inter-vehicle ad-hoc communication protocol for acquiring local traffic information. In *Proc. of 11th World Congress on Intelligent Transport Systems*, pages SP05, No.3 (CD–ROM), 2004.