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Adaptive Routing Algorithm with QoS Support in Heterogeneous Wireless Network

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Abstract-*With the progress of wireless radio technology and telecommunication, various wireless specifications and protocols form the unhandy heterogeneous network. The routing problems in heterogeneous network become popular researches nowadays. In this paper, we integrate cellular (3G) network and Mobile Ad-Hoc Network (MANET) into a hybrid network. This hybrid network is called heterogeneous wireless network (HWN) with multi-cells architecture to overcome the weakness of cellular network and Ad-Hoc network. Based on HWN, we propose a routing algorithm with quality of service (QoS) supported for requirements in the original homogeneous cellular network and Ad-Hoc network. Simulation results show that HWN with the proposed algorithm has lower request block rate and shorter transmission time.*

1. Introduction

In recent years, the progress of wireless communication technologies brings convenience to our daily life. Moreover, various wireless personal communication systems have been deployed all over the world. Hence, mobile users can communicate with others and access the Internet anytime and anywhere. Therefore, wireless networks must provide ubiquitous communication capability and information access regardless of user's location.

There are many wireless service devices deployed according to the requirements and the characteristics of networks. Furthermore, the Ad-Hoc network is another network type worthy to mention about. It is a wireless network without communication infrastructure. It is characterized by dynamic topology due to mobile node mobility, limited bandwidth, and limited battery power. Each mobile host (MH) operates not only as a host but also a router. It forwards the packet to other nodes by using peer-to-peer communication. There are many researches about efficiently finding out the "multi-hop" routing paths [1,2,3] and discussing some resource factors needed to be considered in such "homogeneous" environment [19,20]. These routing algorithms can be mainly classified into two categories. One is *proactive* protocol, which all MHs proactively maintain their neighbors' information table. When some MHs trigger route request messages, this protocol can be aware of the neighboring MHs' state without any extra detection and delay. Therefore, neighboring MHs must periodically exchange the information to avoid the out-of-date of their information table. The other category is *reactive* protocol, which couples with the on-demand nature. Such protocol eliminates the need of updating table information among neighboring MHs. When an MH uses such protocol, it takes some waiting time during the process of discovering a route. However, there are other issues, such as time complexity, communication complexity, multicast capability, etc. can be found in [17].

According to many various features and limitations of wireless communication technologies, a variety of heterogeneous wireless networks are formed, but most of them are impractical. Users still use the single wireless communication technology for special purpose nowadays. Currently, many researchers bring up the project of 4G or called B3G. The main goal of 4G projects is to integrate all kind of nowadays heterogeneous networks [7]. However, the project faces many research challenges and issues, such as handoff, pricing and billing, location coordination, etc. [4,15]. However, most researches only offer the conceptual model or provision toward the 4G [5,6,7]. In this paper, we consider the heterogeneous wireless network (HWN) that is the hybrid network of popular 3G cellular network and Ad-Hoc network. We take the advantages of the large-scale 3G systems and the high transmission rate in Ad-Hoc network. HWN can reduce the block rate of the Internet access and support larger coverage of Ad-Hoc network. Moreover, we propose an adaptive routing algorithm without additional hardware cost.

The rest of the paper is organized as follows. In Section 2, we introduce the heterogeneous wireless network architecture and the existing algorithms about HWN. In Section 3, we present our adaptive routing algorithm with QoS (Quality of service). In Section 4, we give the simulation environment and parameters. The results are also given in Section 4. At last, the conclusion is drawn in Section 5.

2. Heterogeneous wireless network architecture

Nowadays, there are many researches about the routing protocol and algorithm in HWN toward 4G [11,12,13,14]. However, most of these researches only offer the conceptual network architecture without details [14] or just care only single base station (BS) assumption without considering the congestion problem [12,18]. Moreover, these researches only study the routing algorithm of original cellular network [13] or original Ad-Hoc network [12] without considering both network requirements.

The heterogeneous wireless network we consider here integrates the features of the cellular network and Ad-Hoc network. In Fig. 1, we assume that each MH equips with the cellular interface and Ad-Hoc interface. Fortunately, there are many companies such as GTRAN WIRELESS [8] and Texas Instruments [9] offering dual-mode integrated interface recently.

The HWN architecture mentioned here considers only the commercial applications. We take into account many factors of the great majority commercial network applications such as availability assurance, reliability, and throughput to insure the quality of service for transmitting data.

To improve and manage these factors, we must solve two problems raised in the HWN. First, the HWN supports the specific source and destination relation in original Ad-Hoc network. When specific source node has multiple routing paths to forward data to destination, an effective routing path of considering the factors mentioned above is selected. Second, based on the multi-cells architecture of HWN, an effective method of balancing the data traffic is needed to enhance the total data throughput or the number of serviced users. The detailed algorithm of solving these two problems is described in Section 3.

In HWN, MH can have different behaviors than that in the homogeneous network.For examples, in Fig. 1 there are three types of communication for mobile devices. First, if a source (S1) wants to deliver data packets to destination (D1), S1 delivers the packets to D1 by multi-hop routing through intermediate nodes without any assistance in the cellular network. In other words, S1 can deliver packets to D1 with the Ad-Hoc network by using IEEE802.11 interface. Second, if S2 and D2 are in different cells and close to each other, S2 can deliver packets to D2 through the Ad-Hoc network without wasting the bandwidth of the base station. Third, when S3 wants to deliver packets to D3 in different cell that is not adjacent to the source S3 and BS1, S3 will use the cellular network to deliver data. Hence, S3 will occupy the bandwidth (uplink) of BS1. Then, packets are delivered through the fixed network to BS2. Moreover, BS2 will use some bandwidth (downlink) to deliver packets to D3. In addition, MH can connect to the Internet (fixed network) through the cellular network. It also occupies the bandwidth (uplink or downlink) of base station.

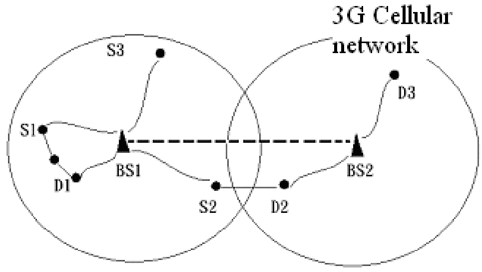

Figure 1. Source and destination relation in heterogeneous wireless network architecture

3. The proposed algorithm

Based on the hybrid network of Ad-Hoc network and cellular network to form the heterogeneous wireless network, we propose two major processes of the *ARA* (adaptive routing algorithm): *adaptive routing discovery process* (ARDP) and *load balancing process (LBP).* In the following, we describe the *ARDP* and compare it with *H-DSR* (heterogeneous dynamic source routing).

In Section 3.1, we present the simplified flowchart of the overall algorithm. In Section 3.2 we give some reasons why we use the route discovery algorithm based on the *reactive routing protocol*. In Section 3.2.1, we describe the details of route discovery algorithm modified by dynamic source routing (DSR) in homogeneous wireless environment to fit the HWN and the RREQ (route request) message format. This route discovery algorithm is called *H-DSR*. In Section 3.2.2, we present the route selection and route metric function of *ARDP*.

3.1. The overall algorithm

The simplified flowchart of the overall *ARA* (adaptive routing algorithm) is illustrated in Fig. 2. More specifically, we also describe the network interface used by MH and the state in details used by MH in Fig. 2. However, we also classify the traffic load of requirements into two parts simply: specific source and destination relation traffic and Internet access traffic. The difference between these two traffic loads is the destination of the request. The destination can be the MH or the server connected to Internet by fixed network. Therefore, if the application of MH can decide the requirement of the Internet access, the MH can send the RREQ messages by only cellular interface through the fixed network to the Internet server to the registered cell without flooding the RREQ messages by dual-mode interface.

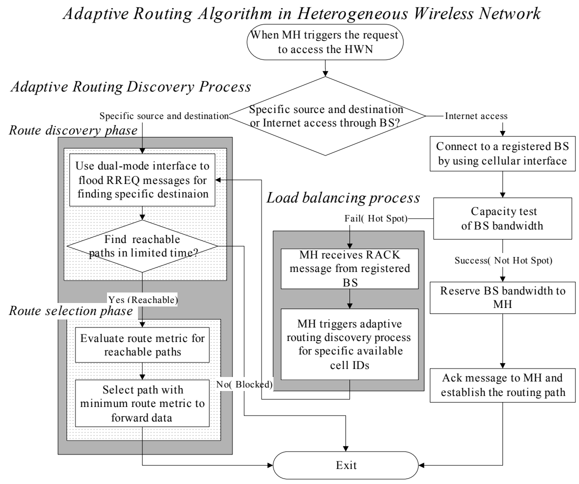

Figure 2. The overall algorithm

When an MH wants to access the Internet, it connects to the registered cell. Then, BS runs the capacity test to check if BS has enough bandwidth to this request or not. Then, BS sends Ack message backward to MH. If the capacity test can be succeeded, the routing path of data transmission is established. If the capacity test fails, the "Load Balancing Process" starts.

If an MH triggers the specific source and destination requirement to find a specific MH in HWN, the adaptive routing discovery process starts to find the specific destination by using dual-mode interface. If reachable routing paths are found, the proposed routing algorithm evaluates the route metric for each reachable route and selects one routing path with minimum route metric to transmit data. Otherwise, the request is blocked.

3.2. Adaptive routing discovery process

In HWN, a novel routing algorithm is proposed to find out the intelligent path to forward or deliver data packets in it. As discussed in Section 1, there are two types of routing protocol in Ad-Hoc network, one is proactive routing, and the other is reactive routing. The period of updating-table time T in proactive routing protocol relies on the routing table update mechanism [17]. When T is low, out-of-date routing table information in MH is unavoidable. When T is high, there will be unnecessary overhead of updating routing table. Furthermore, not all of MHs deliver and receive data in each time cycle. Therefore, some updating messages in proactive routing protocol are unnecessary, and the implement of such protocol is not included in the proposed algorithm.

Based on the reasons mentioned above and the performance of link-level simulation analysis in [12,16], our algorithm uses reactive routing which has more advantages and better fit for HWN. We also separate the route discovery process into two phases: route discovery phase and route selection phase. In Sections 3.2.1 and 3.2.2, we describe how ADRP and H-DSR works, and discuss the difference between them, respectively.

3.2.1. Route discovery phase. Our ARDP (adaptive routing discovery process) and H-DSR (Heterogeneous version of Dynamic Source Routing) is the modification of the reactive DSR (Dynamic Source Routing) routing protocol in homogeneous network [10]. In this phase, H-DSR and ARDP work the same in detail.

During routing discovery phase, we let BS (Base Station) act as MH when joining the routing discovery. However, the transmission range, bandwidth, frequency band, delay of transmission and the mobility are different. Moreover, we assume that each node (MH or BS) has a unique IP. Then, the "Source ID" field and "Destination ID" field in RREQ can be filled with specific IP.

When some MHs trigger the access request in HWN, BS as well as a mobile host joins the routing discovery process, which leads the waste of the uplink bandwidth in BS. Therefore, when node receives the RREQ (Routing Request) message, it checks the complete route filed in RREQ. If the partial routing path exists in routing cache, node will discard the RREQ message. Otherwise, it re-floods the packet to reachable neighbors and appends the host id in the complete route filed. If the destination is reachable, the RREP message contains the complete routing path information toward the source. Hence, the routing path is established.

Through the aid of BS, the original unreachable source and destination pair in homogeneous Ad-Hoc network can find another path to deliver packets. The request block rate can be reduced. However, when BS receives the RREQ message, it can check the VLR (Visitor Location Register) to avoid re-flooding messages to reachable MHs. It can send the RREQ message to reachable MH that is registered in its VLR or check the HLR (Home Location Register) to forward the RREQ message to specific destination in other BS through cellular network. The RREQ message format and field is shown in Fig. 3.

Source ID	Request ID	Destination ID	TTL	Complete Route	Request Bandwidth
			HOP		

Figure 3. The RREQ message format

The intermediate node can be a MH or BS. When the intermediate node receives the RREQ message, it checks the "TTL" and "Hop" fields in RREQ message to decide to discard the message or not. Moreover, the traffic of flooding message can be eased of the same source ID request when intermediate node receives the RREQ message.

If the intermediate node is BS, it checks the VLR (Visitor Location Register) database to find the reachable MHs in this BS when the available bandwidth of BS can service the request of source. If the destination is reachable, BS sends RREQ message to the destination node and appends the host id and available bandwidth of itself. Otherwise, BS checks the HLR (Home Location Register) to find the registered users in other BS. Then, it appends the host id and available bandwidth in "Complete Route" field in RREQ message. Then, the BS forwards RREQ messages to reachable BS through fixed network to find destination node, such as S3-BS1-BS2-D3 relation in Fig. 1.

When the host is MH, it checks the "Destination ID" field. If the host is the destination, the host sends the RREP message backward to the source node. Otherwise, the MH appends host id and available bandwidth in "Complete Route" field in RREQ message and forward to reachable next-hop by dual-mode interface. Moreover, when the intermediate node receives the RREP message, it updates the available bandwidth of itself and forwards the RREP message to next-hop recorded in the RREP message.

3.2.2. Route selection phase. The proposed *ARDP* (Adaptive Routing Discovery Process) and *H-DSR* is the same in route discovery. However, the major difference of our *ARDP* and proposed *H-DSR* is in the routing selection phase that bases on different metric function. The routing metric of *H-DSR* and DSR in homogeneous Ad-Hoc network is based on the shortest path. We design the routing metric function for considering the transmission time and number of intermediate nodes in our *ARDP*. The routing metric and routing selection functions of *ARDP* and *H-DSR* are described in the following.

We assume that all the *nodes* in HWN are a set *S*.

$$S = \{N_1, N_2, N_3, \ldots, N_k \mid k \text{ is number of nodes } (MH \text{ or } BS) \text{ in } HWN\}$$

When the *route discovery process* finished, multiple paths may be discovered. Then, the routing paths discovered can be defined as:

$$\text{RouteDiscovery}(N_{src}, N_{dest}) = \{R_1, R_2, R_3, \ldots, R_n \mid N_{src}, N_{dest} \in S \text{ and } N_{src} \neq N_{dest}\} \quad (1)$$

n : the number of paths found

and

$$R_i = \{N_{src}, N_1, N_2, \cdots, N_{dest}\},\ 2 \le |R_i| \le \text{Max\_Hop} + 1 \quad (2)$$

Max_Hop : the max number of intermediate nodes in R_i

$|R_i|$: number of nodes in R_i

However, R_i must satisfy the following rule:

$$\text{dist}(N_j, N_{j+1}) \le T(N_j),\ \forall N_j, N_{j+1} \in R_i,\ 1 \le j \le |R_i| - 1 \quad (3)$$

$T(N_i)$: transmission range of N_i

$\text{dist}(N_j, N_{j+1})$: distance between N_j and N_{j+1}

Moreover, the RM (routing metric) function of the *H-DSR* is defined as follows.

$$RM_{H-DSR}(R_i) = |R_i|,\ 1 \le i \le n \quad (4)$$

n : number of path found in route discovery phase

Moreover, the RS (routing selection) function of *H-DSR* is defined as:

$$RS_{H-DSR}(\text{RouteDiscovery}(N_{src}, N_{dest})) = \min\{RM_{H-DSR}(R_1), RM_{H-DSR}(R_2), \cdots, RM_{H-DSR}(R_n)\} \quad (5)$$

n : the number of paths found

However, to minimize the transmission time, we should avoid selecting the route discovered with "*bottleneck*". The "*bottleneck*" means the route having one or more nodes whose available bandwidth which is much lower than other nodes in the route. If a route to specific destination node has a "*bottleneck*", the transmission time of this route become longer than other discovered paths. We assume the transmission time of the route is defined as:

$$\text{Transmission Time}(R_i) = \left(\text{Data\_Size} \middle/ \min\{AB(N_1), AB(N_2), \cdots, AB(N_{|R_i|})\} \right) \quad (6)$$

$AB(N_i)$: Available Bandwidth of N_i

However, the actual transmission time of the selected route should plus time of several time slots T_{slot}. But comparing the T_{slot} with *Transmission Time* (R_i) mentioned above, T_{slot} is slight and can be ignored.

For minimizing the transmission time with less intermediate nodes, we design the RM function of *ARDP* as follows

$$RM_{ARDP}(R_i) = [(\text{REQ\_bandwidth} - \text{min\_AB}(R_i)) / \text{REQ\_bandwidth}] + |R_i|,\ 1 \le i \le n \quad (7)$$

REQ_bandwidth : request bandwidth of N_{src}

$\text{min\_AB}(R_i) : \min\{AB(N_1), AB(N_2), \cdots, AB(N_k) \mid \forall N_k \in R_i,\ 1 \le k \le |R_i|\}$

The proposed RS function of *ARDP* is defined as:

$$RS_{ARDP}(\text{RouteDiscovery}(N_{src}, N_{dest})) = \min\{RM_{ARDP}(R_1), RM_{ARDP}(R_2), \cdots, RM_{ARDP}(R_n) \mid n \text{ is the number of paths found}\} \quad (8)$$

More specifically, if $RM_{ARDP}(R_i)$ and $RM_{ARDP}(R_j)$ are the same, we select the route with higher average value of available bandwidth.

When the intermediate nodes in the routing path leave, it causes the RERR (Route Error) messages to send toward the source node. When the source node receives the RERR message from the intermediate nodes, the source node re-triggers the *adaptive routing discovery process* again if the transmission data is not finished.

3.3. Load Balancing Process

The capacity of BS is usually limited. Here, a *capacity test* of BS is introduced. If the *capacity test* of reachable BS is failed, this BS becomes the "Hot Spot" (congestion spot). When an MH wants to access the Internet through the "Hot Spot" BS, the *load balancing process* triggers. The goal of the process is to find out another available routing path to access the Internet through other available BS when the originally registered BS of MH becomes "Hot Spot". In other words, we propose the extension of the original cellular network requirement through the Ad-Hoc network in multi-cells. In addition, the goal of this process is to reduce the block rate of original cellular network.

The *capacity test* of BS mentioned above can be written as follows.

$$\text{Total bandwidth - reserved bandwidth} \geqq \text{request bandwidth of MH}$$

Moreover, there are 4 steps in the *load balancing process*:

Step 1. When BS becomes "Hot Spot" (congestion spot), it checks the routing table information collected by the fixed network to find neighboring BS which is available to access.

Step 2. The "Hot Spot" BS fills the neighboring cells ID in RACK (Route ACK) message. Then it sends RACK message to the source node.

Step 3. The source node triggers the routing discovery process through Ad-Hoc network to find the other path that can access the neighboring cells ID recorded in the RACK message.

Step 4. If step 3 success, the routing path selected by routing metric of proposed ARDP to the neighboring cells is established. Otherwise, the request will be blocked.

For example, in Fig. 1 if the BS1 becomes "Hot Spot", the request initiator of S2 will access the network by such a routing path S2-D2-BS2. Through the aid of *load balancing process,* the request block rate can be reduced compared to the original cellular network.

4. Simulation

In this section, we present the performance evaluation of the proposed *ARA* (adaptive routing algorithm) in HWN. In order to form HWN environment, we distribute the BS as a 3x3 matrix. The coverage of each BS is 1000*1000 square meters. We assume that it is an all-IP environment which each MH and BS has unique IP as ID. The distributed position of MHs in the HWN is randomly generated and located. All MHs are registered to BS.

The handoff scheme of HWN is based on the "hard handoff". When MH moves to neighboring cells, it triggers the routing discovery process to establish the new route toward the new cell and it drops the previous connection immediately.

The specifications of the dual-mode interface about bandwidth and transmission range are set initially as the ideal maximum value of respective standard [21, 22].

Table 1. Simulation Parameter

Parameters		Value
Number of BS		9
Coverage of BS		1000*1000 (m^2)
Max hops of each route		10
Pausing Time		1s
Request bandwidth	Class 1	50~100 kbps
	Class 2	100~200 kbps
	Class 3	200~400 kbps
	Class 4	400~600 kbps
Mobility Model	Random Way-Point model	
MH Mobility	Class 1	0 m/s (fixed)
	Class 2	1~3 m/s (slow)
	Class 3	4~8 m/s (medium)
	Class 4	9~12 m/s (fast)

The classes of request bandwidth are set according to the service capabilities in 3GPP standardization [22] and given to MH randomly. Moreover, we vary the maximum moving speed of MHs from 0, 3, 8, 12 m/s and divide them into 4 classes. The maximum hop of forwarding data is set as 10. More specifically, Table 1 presents the summarized simulation parameters in our simulation environment. We also give the definition of *request block rate* as follows.

$$\text{Request block rate} = \frac{\text{number of blocked request to access the network}}{\text{total number of requests to access the network}}$$

Fig.4 presents the *transmission time* mentioned in Section 3. We compare the *transmission time* between the *H-DSR* and the proposed *ARA* (adaptive routing algorithm). In Fig. 4, the transmission time of the proposed *ARA* is about 5~22% lower than that of *H-DSR.* The size of deliver data is set to 1Mb.

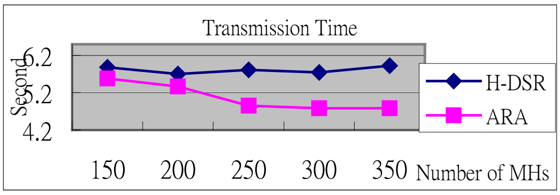

Figure 4. Transmission time of H-DSR vs. transmission time of ARA

The comparison of *request block rate* in HWN is shown in Fig.5. The block rate of proposed *ARA* (adaptive routing algorithm) is about 15~20% lower than the *H-DSR*. In other words, the proposed *ARA* serves more connections in HWN. In addition, the algorithm with HWN can reduce block rate about 50% than that without HWN.

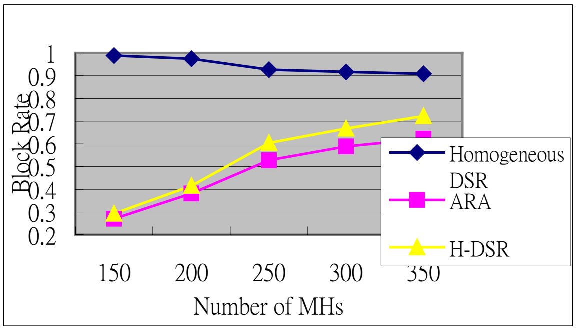

Figure 5. Request block rate of H-DSR vs. Request block rate of ARA

In Fig. 6, the comparison of *request block rate* of ARA without *load balancing process* and ARA with *load balancing process* in multi-cells environment is presented. The proposed ARA with *load balancing process* reduces the block rate of request. In other words, we serve more than 10% MHs to access the HWN through the *load balancing process*.

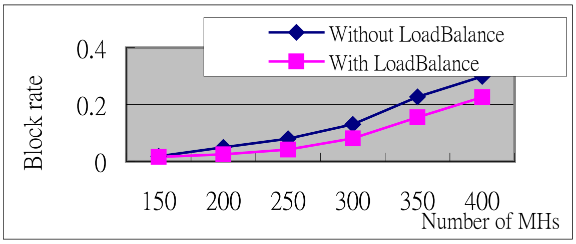

Figure 6. Request block rate without LBP (Load balancing process) vs. block rate with LBP

5. Conclusion

In the paper, we have considered a novel network HWN which is the hybrid of Ad-Hoc network and cellular network with multi-cells. We have also proposed the ARA (adaptive routing algorithm) which consists of two major processes: adaptive routing discovery process and load balancing process.

Through the HWN architecture and the proposed adaptive routing algorithm, we can reduce block rate about 50%. In other words, HWN can serve 50% more users than the homogeneous Ad-Hoc network architecture. The transmission time by the proposed adaptive routing algorithm is about 5~22% lower the heterogeneous dynamic source routing. Moreover, the load balancing process in multi-cells can reduce almost 10% request block rate.

6. References

[1] X. Zhang, and L. Jacob, “Adapting Zone Routing Protocol for Heterogeneous Scenarios in Ad Hoc Networks”, *International conference on parallel processing (ICPP)*, Oct., 2003.

[2] G. R. Dattatreya, S. S. Kulkarni, H. Martinez, and R. Soto, “Adaptive control of heterogeneous ad hoc networks”, *IEEE International Conference on Systems, Man, and Cybernetics*, Volume: 5, pp.3431 -3436, Oct., 2000.

[3] J. Broch, D. A. Maltz, and D. B. Johnson, “Supporting hierarchy and heterogeneous interfaces in multi-hop wireless ad hoc networks”, *(I-SPAN) Proceedings on Parallel Architectures, Algorithms, and Networks*, pp.370-375, Jun., 1999.

[4] A. Bria, F. Gessler, O. Queseth, R. Stridh, M. Unbehaun, Wu. Jiang, J. Zander, and M. Flament, “4th-Generation Wireless Infrastructures: Scenarios and Research Challenges”, *IEEE conference on Personal Communications*, vol.8, Dec., 2001.

[5] V. Marques, R. L. Aguiar, C. Garcia, J. I. Moreno, C. Beaujean, E. Melin, and M. Liebsch, ” An IP-based QoS architecture for 4G operator scenarios”, *IEEE Journal on Wireless Communications*, vol.10, no.3,pp.54-62 , Jun., 2003.

[6] L. Becchetti, F. Delli Priscoli, T. Inzerilli, P. Mahonen, and L. Munoz, ” Enhancing IP service provision over heterogeneous wireless networks: a path toward 4G”, *IEEE Journal on Communications Magazine*, vol.39, no.8, pp.74-81, Aug.,2001.

[7] W. Kellerer, C. Bettstetter, C. Schwingenschlogl, and P. Sties, ” (Auto) mobile communication in a heterogeneous and converged world”, *IEEE Journal on Personal Communications* , vol.8, no.6, pp.41-47, Dec., 2001.

[8]http://www.gtranwireless.com/newsevents/pressreleases_20020318_DotSurferDemo_english.php

[9]http://focus.ti.com/docs/apps/catalog/general/applications.jhtml?templateId=977&path=templatedata/cm/general/data/bband_80211_mot

[10] D. B. Johnson, and D. A. Maltz, “Dynamic Source Routing in Ad Hoc Wireless Networks.”, *IEEE Transactions on Mobile Computing*, vol.353, pp.153-181, 1996.

[11] R. Chang, W. Chen, and Y. Wen, “Hybrid wireless network protocols”, *IEEE Transactions on Vehicular Technology*, vol.52, no.4, pp.1099–1109, Jul., 2003.

[12] H. Luo, R. Ramjee, P. Sinha, L. Li, and S. Lu, ”Cellular and hybrid networks: UCAN: a unified cellular and Ad-Hoc network architecture”, *ACM Proceedings conference on Mobile computing and networking*, Sep., 2003.

[13] H. Wu, C. Qiao, S. De, and O. Tonguz, “Integrated Cellular and Ad Hoc Relaying Systems: iCAR.”, *IEEE Journal on Selected Areas in Communications*, vol.19, no.10, pp.2105-2115, Oct., 2001.

[14] E. H. Wu, Y. Z. Huang, and J. H. Chiang,”Dynamic Adaptive Routing for Heterogeneous Wireless Network.”, *IEEE Conference* on *Global Telecommunications*, vol.6, pp.3608–3612, Nov., 2001.

[15] U. Varshney, and R. Jain,” Issues in emerging 4G wireless networks”, *IEEE Journal on Computer*, vol.34, no.6, pp.94–96, Jun., 2001.

[16] I. Gruber, G. Bandouch, and L. Hui, ”Ad hoc routing for cellular coverage extension”, *IEEE conference on Vehicular Technology*, vol.3, pp. 1816–1820, Apr., 2003.

[17] E. M. Royer, and C. K. Toh, ” A review of current routing protocols for ad hoc mobile wireless networks”, *IEEE Journal on Personal Communications*, vol.6, no.2, pp.46–55, Apr., 1999.

[18] C. S. Wijting, and R. Prasad, ”Evaluation of mobile ad-hoc network techniques in a cellular network”, *IEEE Conference on Vehicular Technology*, vol.3, pp. 1025-1029, Sep., 2000.

[19] M. S. Jian, P.L. Wu, and C. N. Lee, “On-demand flow regulated routing for ad-hoc wireless network” *IEEE Conference on Wireless Personal Multimedia Communications*, vol.1, pp. 242–246, Oct., 2002.

[20] M. S. Jian, C. C. Chen, and C. N. Lee, “Ad hoc On-Demand Resource Management using Improved Rank-based Fitness Assignment” , *Proceeding On WPMC*, pp.256-258, Oct., 2003.

[21] “IEEE Std. 802.11b-1999/Cor.1”, *IEEE standard for information technology - telecommunications and information exchange between systems*, 2001

[22] H. Holma, and A. Toksala, *WCDMA FOR UMTS, 2nd ed.* , John Wiley & Son Ltd. , England, 2002.