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Hybrid Wireless Network Protocols*

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Abstract - The traditional BS-oriented wireless network has the characteristics of reliability and higher performance. However, the ad hoc wireless network topology is more desirable because of its low-cost, plug-and-play convenience, flexibility, and minimal human interaction requirements. Its usage of bandwidth and battery power is more efficient. In this paper, we propose a hybrid method to get the advantages and avoid the problems of ad hoc wireless network. We allow 2-hop-direct-transmission within the BS-oriented networks. The hybrid protocol has more flexibility, reliability, and high performance than the traditional wireless network protocols. The simulation results show that the 2-hop-direct-transmission has a lower non-complete probability. If the communicators were always within a 2-hop-direct-transmission area, it will improve the rate of complete communication about 20%.

Keywords : *BS-oriented Networks, Ad hoc Networks, Mobility, Wireless Networks.*

1. INTRODUCTION

Mobile Hosts (MHs) and wireless networking are becoming widely available, and extensive work has been done recently in integrating these elements into traditional networks such as the Internet. The rapid expansions of wireless communication technologies such as cellular network and wireless LAN are making it possible to support universal network connectivity for mobile computers. This motivates a new generation of mobile switching networks to serve as infrastructure for many services. Mobile networks deployed in the next few years should be capable of smooth migration to future broadband services based on high-speed wireless access technologies, such as WATM (Wireless Asynchronous Transfer Network) [1,12]. Motivated by the growing acceptance of ATM as a standard for broadband multimedia communication, in 1996 the ATM Forum and ETSI (European Telecommunication Standard Institute) started the extension of the current WATM standard to mobile WATM applications [7].

There are two basic types of structure for WLAN : (1) infrastructure WLAN—BS-oriented network. (2) non-infrastructure WLAN—Ad hoc wireless network. The BS-oriented network is more reliable and has higher performance. However, the ad hoc network topology is more desirable because of its low-cost, plug-and-play property, flexibility, minimal human interaction requirements, and especially battery power efficiency. It is suitable for communication in a closed area, for example, in a campus or in a building.

To combine their strength, we would prefer to add BS's to an ad hoc network. In order to save access bandwidth, battery power, and have fast connection, the MHs could use ad hoc wireless network when communicating with each other in a small area. When the MHs move out the transmitting range, the BS could participate at this time and serve as an intermediate node. The proposed method also solves some problems, such as BS failure and weak connection under ad hoc network. The MH can communicate with one another in a flexible manner and freely move anywhere with seamless handoff.

There are many techniques or concepts proposed before for supporting the WLAN with and without infrastructure, such as IEEE802.11, HIPERLAN and ad hoc WLAN. The standardization activities in IEEE802.11 and HIPERLAN have recognised the usefulness of the ad hoc networking mode. The IEEE 802.11 enhances the ad hoc function to the MH. The HIPERLAN combines the functions of two infrastructures into the MH. Contrary to IEEE802.11 and HIPERLAN, the ad hoc WATM LAN concept is based on the same centralised wireless control framework as the BS-oriented system. This assures that MH designed for the BS-oriented system can also participate in ad hoc networking, and that optimal allocation of wireless resources can be made to different services with respect to the required QoS [7].

However, it was still not flexible enough because after transmitted by the ad hoc network, you must continue using this mode. To rectify this, we propose a flexible protocol that allows the hop-by-hop direct transmissions under the BS-oriented network. The proposed method is called "Hybrid Wireless Network Protocols". A 2-hop-direct-transmission allows for more flexibility and reliability. We also consider the location management and handoff procedures when the MH moves around. These functions are almost the same as the traditional BS based wireless network. But we make some changes when the transmission mode changes from direct transmission to BS-oriented or BS-oriented to direct transmission.

The rest of this paper is organized as follows. Section 2 discusses the weaknesses of BS-oriented wireless networks

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and ad hoc wireless networks. The proposed method is explained in Section 3. Performance evaluations by simulations are presented in Section 4. Finally, Section 5 is the conclusions.

2. The Problems of BS-oriented and Ad hoc Networks

In the BS-oriented network, BS manages all the MHs within the cell area and handles handoff procedures [3,9,11,13]. It plays a very important role for WLAN. If it does not work, the communication of MHs in this area would be disrupted. For example (see Fig. 1), if BS2 fails, all MHs under the BS2 could not communicate with others. Under this situation, we hope MH3 could still transmit messages to others without BS2. Therefore, to increase the reliability and efficiency of the BS-oriented network, we add MH to MH direct transmission capability. However, we restrict it to at most two hops such that this new enhancement will not increase the protocol complexity too much.

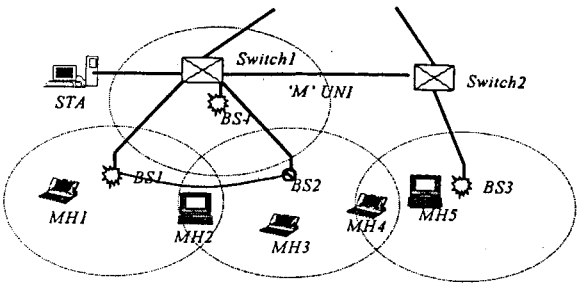

Fig. 1 BS failure problem

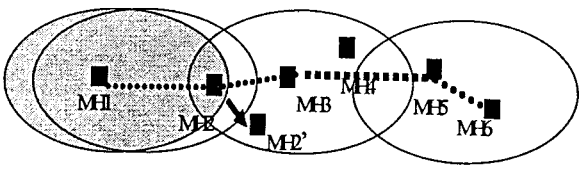

Fig. 2 Routing caused by mobile

Besides, it is not easy to rebuild or maintain a connection in the ad hoc network [2,4-6,8,14]. When the connection is built, it will be disrupted any time when one MH moves out the connection range. For example (see Fig. 2), MH1 sends the packets to MH6 through MH2. MH2 forwards the packets to MH3. Each MH forwards the packet hop by hop until the packets arrive at the destination (MH6). When MH2 moves out the covering area of MH1, MH1 must find another path. Since MH moves randomly, the frequent rerouting will decrease the throughput and increase the delay. Another problem is that there may be no MH to act as an intermediate node for forwarding the packet to the destination. Forced termination would occur if this happened during a connection. For example (see Fig. 3), the path from MH2 to MH3 is unique. If MH3 moves out of range, the connection from MH1 to MH6 will be disrupted.

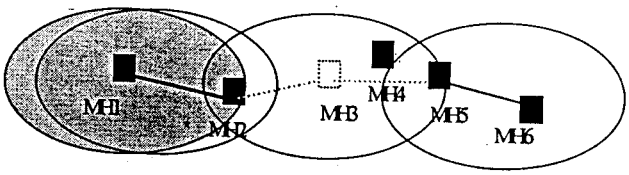

Fig. 3 Disrupted connection

3. The Proposed Methods

We propose two methods: "1-hop-direct-transmission within BS-oriented" and "2-hop-direct-transmission within BS-oriented". The former is simple and controlled by the signal strength, and the later should include the data forwarding and implementation of routing tables.

In order to achieve the integration of the BS-oriented method and direct transmission method, we define some control messages :

1. ACK/ACCEPT/REJECT: used to indicate the acknowledgment, acceptance, or denial of connection request or handoff.
2. DIRECT: used by a MH to inform a BS that the transmission mode is in direct transmission mode.
3. GREET: sent by a newly arrived MH to a new BS.
4. SEARCH: used to find the destination. Each MH receiving this message must check the destination address for a match.
5. SETUP: used to establish a new connection.

3.1 One-hop-direct-transmission within BS-oriented

"1-hop-direct-transmission within BS-oriented" defines the situation where direct transmission is executed when the receiver is in the covering range of the sender. We consider the location management and handoff procedure when the MH moves around. These functions are the same as the traditional ones. But we enhance the handoff functions to handle the case when the transmission mode changes from 1-hop-direct-transmission to BS-oriented or vice verse.

However, the key issue is to decide whether 1-hop-direct-transmission or BS-oriented transmission method should be used. When the sender broadcasts the connection request message, both BS and MH within the sender's signal covering area would receive this message. Each MH receiving the message will check the destination ID. If the destination ID matches itself, the transmission would use the 1-hop-direct-transmission method. Otherwise, the BS would be used for connection. When the destination moves out the covering area, the BS would do handoff procedures. On the other hand, when the MH moves into the covering range, the transmission will stop going through the BS and change to 1-hop-direct-transmission.

The basic operations are described as follows:

(1) Situation 1: Direct Transmission (Fig. 4)

The sender broadcasts the request message to its neighbors. If the destination can receive this message, it

responds the ACK to the sender to enter direct transmission mode. Meanwhile, the BS receiving the same message sends the 'SETUP' message to the destination. Then the MH responds the 'DIRECT' message to inform the BS that it has direct connection with sender. After the sender receives the ACK, it will setup the connection and the transmission will be using 1-hop-direct-transmission mode.

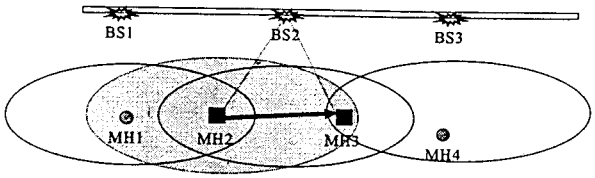

Fig. 4 1-hop-direct-transmission mode

(2) Situation 2: BS-oriented mode (Fig. 5)

When the destination is not in the sender's covering area, it can not receive the message. Meanwhile, BS of the sender receives the message, routes to destination and builds the connection. After the connection is built, the transmission mode is BS-oriented.

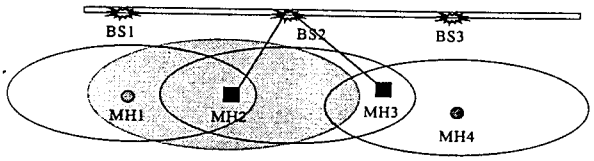

Fig. 5 BS-oriented transmission mode

Because the MH migrates randomly, the location management and handoff procedure must be handled for both situations. In Situation 1, before the MH fully moves out the covering area, the handoff procedure must be executed. For example (see Fig. 6), as the MH3 moves out of sender's covering area, the new connection from MH2, BS2 to MH3' or MH2, BS2, BS3 to MH3' must be built and BS should buffer the packets for a period. As the 'GREET' message sent by MH3' is received by BS, the packets will be downloaded to the destination (MH3') by BS.

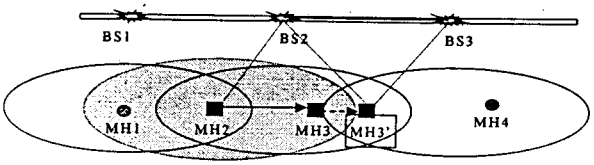

Fig. 6 Handoff procedure

Another case is that the distance between sender and receiver is within the covering area. Only when the MH wants to do handoff, the transmission mode will change to the 1-hop-direct-transmission. For example (see Fig. 7), when the MH3 moves to the MH3', this satisfies the condition of 1-hop-direct-transmission. Since the signal is strong enough, the link of MH2, BS2, BS3, and MH3' would be cut and MH2 transmits the packets to MH3' directly.

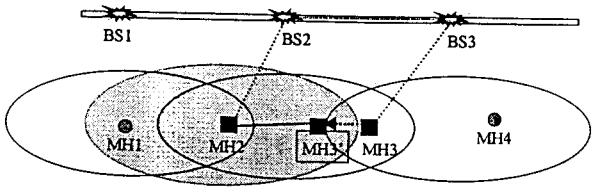

Fig. 7 BS-oriented mode changes to 1-hop-direct-transmission mode

3.2 Two-hop-direct-transmission within BS-oriented

This method will cover a wider area than 1-hop-direct-transmission mode (see Fig. 8). The differences to the 1-hop-direct-transmission mode are described as below:

- ▼ When the receiver is in the covering area or there is one node between the sender and receiver, the sender transmits to the receiver directly. Otherwise the communication would be via the BS.
- ▼ The location management is the same as BS-oriented. The MH must also implement a database of the covering area, which record the information of MH within 1-hop covering range.
- ▼ We enhance the forwarding function of each MH. The connection must be handled as in an ad hoc network because an MH may be an intermediate node.

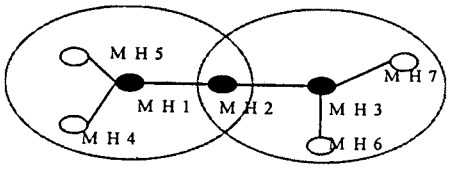

Fig. 8 2-hops-direct-transmission zone

The major mechanisms are described as follows:

(1) Situation 1: direct transmission mode

When the receiver is within the 2-hop transmission area of the sender, the message is transmitted directly. The case of 1-hop-direct-transmission is described before. The 2-hop case is shown in Fig 9.

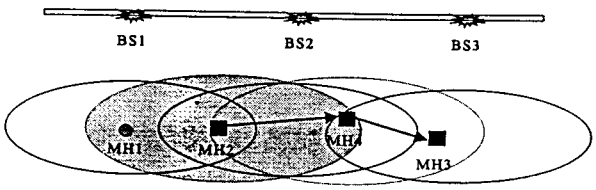

Fig.9 2-hop-direct-transmission within BS-oriented

When MH2 sends out the 'SEARCH' message, MH4 finds MH3 is within its covering area. MH4 sends 'ACK' back to MH2. Then MH2 sends the 'SETUP' message via MH4 to MH3. If there are many MHs in-betweens the sender and destination, the sender chooses the earliest replied message to proceed. As MH3 responds the

'ACCEPT' message via MH4, the direct transmission mode is constructed.

(2) Situation 2: BS-oriented mode

When the destination is out of the 2-hop covering area of sender or no MHs
are between sender and receiver, the sender's BS routes the path to destination and builds the connection. When the BS receives the destinations' 'ACCEPT' message, the connection is completed.

But allowing one hop between the sender and receiver, the location management and handoff procedure will be executed more frequently than 1-hop-direct-transmission mode. In Fig. 10, before MH3 fully moves out the transmission range, the new connection from MH2, BS2, BS3 and MH4 would be built and the BS would buffer the packet for a period. A handoff has to be performed too if MH4 moves out of MH3's signal range.

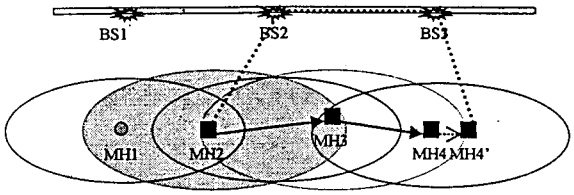

Fig. 10 Handoff: direct transmission mode handoff to BS-oriented mode

However, the situation that the distance between sender and receiver is closing within the 1-hop covering area must be dealt with. The transmission will change to the direct mode. For example (see Fig. 11), when MH3 moves to the MH3', this conforms to the condition of 1-hop-direct-transmission. As the signal is strong enough, the link of MH2, BS2 and MH3' will be cut and MH2 transmits the packet to MH3' directly. The transmission mode changes from BS-oriented to 1-hop-direct-transmission. To accomplish this, MHs must periodically broadcast to the neighbor to inform them: I am your neighbor. The case of changing from BS-oriented mode to 2-hop-direct-transmission mode is not considered here. This is because that much extra information must be exchanged for sender and receiver to know they are within 2-hop area.

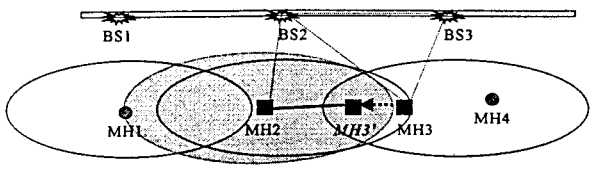

Fig. 11 BS-oriented handoff to 1-hop-direct-transmission mode

4. PERFORMANCE EVALUATION

In order to prove that the proposed method improves the system performance, we compare our modified methods to the traditional BS-oriented and ad hoc networks. We compare the properties of the system by using different environmental values, such as arrival rate, service rate, resident time and others. The performance parameters are:

1. Failure rate: e.g., new call blocking, forced termination, and so on.
2. Cost: e.g., average handoff cost, the number of communication links used, and so on.

4.1 Assumptions

We use SIMSCRIPT to simulate the proposed method. It provides some distribution functions that can help us build the simulation model. For simplicity, we describe the model without the details of the signal propagation, wait for access time, interference and so on. We define an 8*8 array as the cell model (see Fig 12).

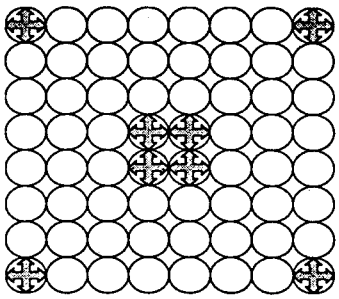

Fig 12 The WLAN topology considered in the simulation

The arrival rate is a random process (e.g., Poisson) and is independent of the movement. A new call is connected when the channel is available; otherwise the call will be blocked. The communication time also follows the exponential distribution. The time of handoff is affected by different parameters. This also determines the MH's movement in different cells. We assume that the MH entrance angle is random and handoff time is random. We consider the simplest scheme called non-prioritized scheme. In this scheme, if no channel is available in the new cell, the handoff call will be forced to terminate immediately. In our simulation, the values of parameters are:

1. New request arrival time = Exponential(0.5)
2. The service time = Exponential(25.0)
3. Cell resident time :
   Exponential (12.0) (BS-oriented)
   Exponential (6.0) (1-hop-direct-transmission)
   Exponential (3.0) (2-hop-direct-transmission)
   Exponential (1.5) (3-hop-direct-transmission)
4. *N*: Number of new calls.
5. *Nh*: Number of handoffs.
6. *Nb*: Number of new calls blocking.
7. *Nf*: Number of forced termination.
8. *Nc*: Number of completion call.

An 8*8 cell mesh is considered in this paper. By controlling the 3-hop-direct-transmission probability, we get the other probabilities as below: (see Fig 13)

1-hop-direct-transmission probability
= 3-hop-direct-transmission probability / 9 (1)

2-hop-direct-transmission probability
= 1-hop-direct-transmission probability * 4 (2)

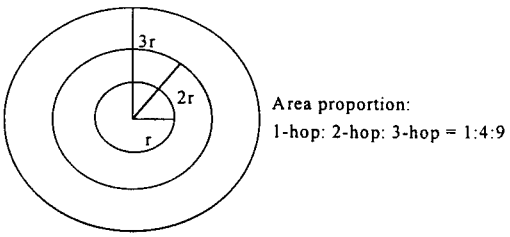

Fig.13 Area proportion

The new call blocking probability (*Pb*) is computed as:

$$Pb = Nb / N \quad (3)$$

and the formula for the forced termination (*Pf*1) is:

$$Pf1 = Nf / Nh \quad (4)$$

$$Pf2 = Nf / N \quad (5)$$

These two formulas are different in the denominator. Formula (4) mainly concerns the average forced termination of each handoff. However, it is confusing because the average handoff times of each MH are different in each model. Therefore, we change the denominator to total number of MHs in Formula (5). It means the average probability of forced termination of each MH. The probability of non-complete (*Pnc*) is :

$$Pnc = (Nf + Nb) / (Nf + Nb + Nc) \quad (6)$$

We also compare the cost and response time. We use the number of links to compare the cost of each operation.

4.2 Simulation Results

In this section, we test the performance of the proposed hybrid protocols by simulations. Define the 2(3)-hop-direct probability as the probability that in mobile communications, the sender and the receiver are within the 2(3)-hop-direct- transmission range. For example, if the 2-hop-direct probability is large, then the sender and the receiver are probably communicating using the 2-hop-direct-transmission protocol instead of base stations. By varying the probabilities, we analyze the system performance and advantages compared to pure BS-oriented systems.

4.2.1 Control the 1-hop-direct-transmission Probability

By controlling the 1-hop-direct-transmission probability, we try to find out whether the 1-hop-direct-transmission method is better than BS-oriented. The results are showed as follows:

1. The number of links of Setup procedure (see Fig 14)
   The two curves overlap on the number of links of setup because the 1-hop-direct-transmission method is controlled by the signal as BS and must via 'SEARCH' and 'SETUP' procedure.

2. The total number of links in handoff procedure: (Fig 15)
   Since each MH's covering area is smaller than that of BS, it is reasonable that direct transmission mode will perform handoff more frequently than BS-oriented mode.

3. New call blocking probability (see Fig 16)
   For each MH uses 1-hop-direct-transmission method, it has less probability of blocking than the frequent handoff. When it has more chance to transmit directly, the bandwidth is double and request less bandwidth than the BS-oriented method.

4. The forced termination probability (Fig. 17):
   The application area of 1-hop-direct-transmission method is half than BS-oriented. As 1-hop-direct-transmission method changes to BS-oriented method, it requests double bandwidth. If the bandwidth is not available, it is forced termination immediately. Therefore, the 1-hop-direct-transmission method is worse than BS-oriented.

5. Non-complete probability (see Fig 18)
   The non-complete probability combines new call blocking probability and forced termination probability. It is a good performance measure. From the trend of curve, The 1-hop-direct-transmission method is better than the BS-oriented method. When the direct transmission is in small area, it can get smaller non-complete probability.

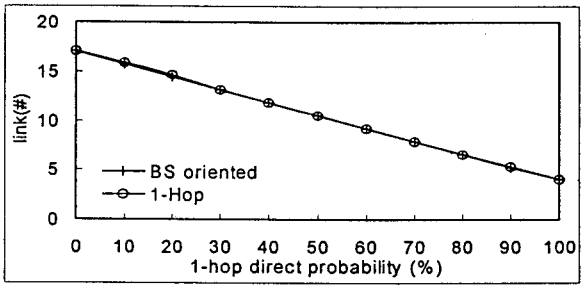

Fig. 14 The cost of setup: 1-hop probability

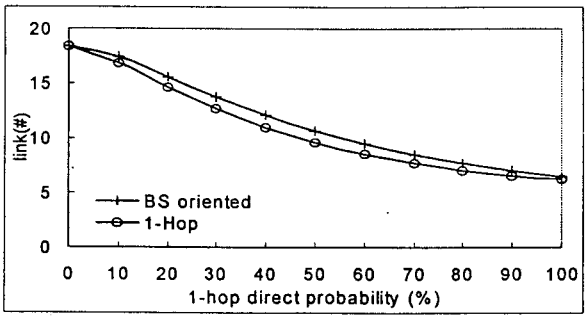

Fig. 15 The total cost of handoff: 1-hop probability

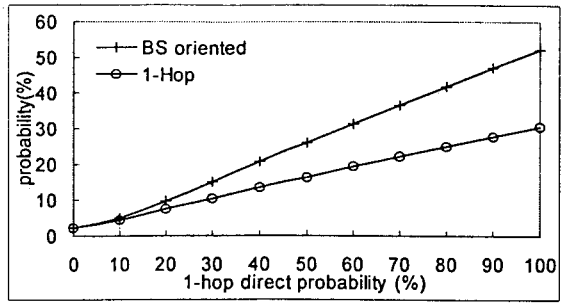

Fig. 16 New call blocking: 1-hop probability

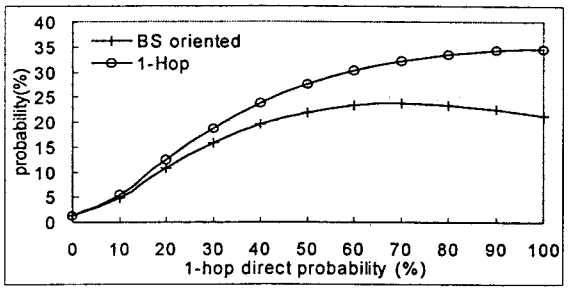

Fig. 17 Forced termination: 1-hop probability

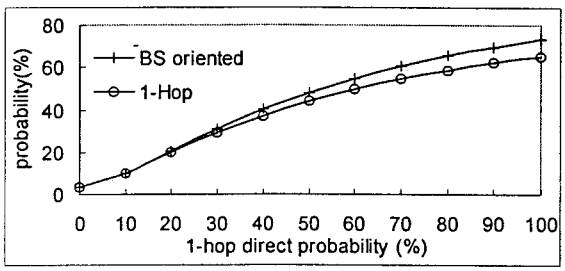

Fig. 18 Non-complete probability: 1-hop probability

4.2.2 Control the 2-hop-direct-transmission Probability

By controlling the 2-hop-direct-transmission probability, we try to find out whether the 2-hop-direct-transmission is better than 1-hop-direct-transmission or BS-oriented. The results are showed as follows:

1. The number of links of Setup procedure (see Fig 19)
   The direct transmission mode should have better air wave link utilization than the BS-oriented. As the 2-hop-direct-transmission probability increases, the number of links decreases.

2. The total number of links in handoff procedure:
   Since each MH's covering area is smaller than that of BS, it is reasonable that direct transmission mode will perform handoff more frequently than BS-oriented mode. (see Fig 20)

3. The forced termination probability:
   We compare formula (4) and formula (5) in Fig 21 and Fig 22. In Fig 21, the forced termination probability of 1-hop-direct-transmission and BS-oriented is close. The reason is that the MHs must exchange information periodically. But it has more bandwidth for transmission when the transmission area is small. It compensates for frequent handoff. In Fig 22, which is computed by formula (6), it shows the 2-hop-direct-transmission has less forced termination probability.

4. New call blocking probability (see Fig 23)
   According to the assumption, once a new request can not get the bandwidth, it will be blocked. For each MH uses 2-hop-direct-transmission method, it has less probability of blocking than the frequent handoff. When it has more chance to transmit directly, it economizes more bandwidth for others to use. Therefore, when the probability of communication within 2-hop is larger than 25%, the 2-hop-direct-transmission can get smaller new call blocking probability.

5. Non-complete probability (see Fig 24)
   From the trend of curve, the 2-hop-direct-transmission method increases the slowest. The 1-hop-direct-transmission method is better than the BS-oriented method. When the direct transmission is in small area, it can get smaller non-complete probability.

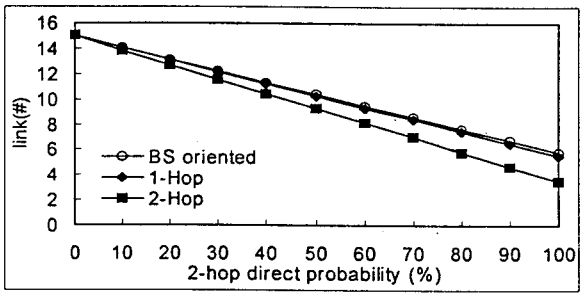

Fig. 19 The cost of setup: 2-hop probability

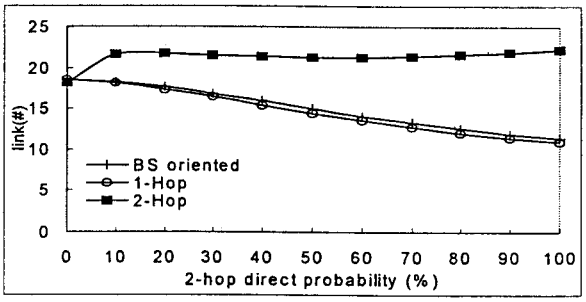

Fig. 20 The total cost of handoff: 2-hop probability

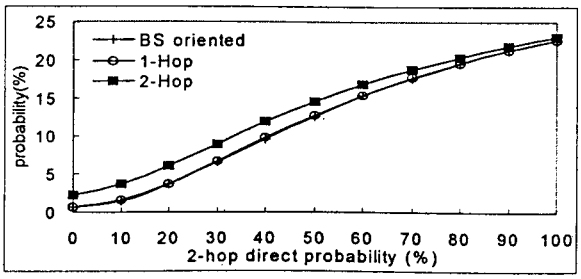

Fig. 21 Force termination: 2-hop probability

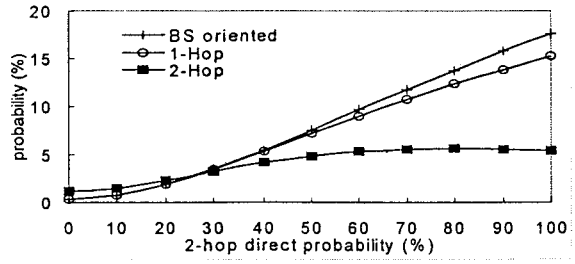

Fig. 22 Average forced termination: 2-hop probability

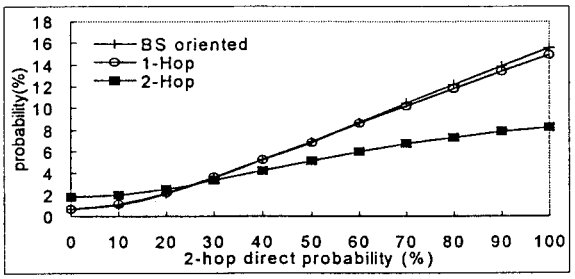

Fig.23 The new call blocking: 2-hop probability

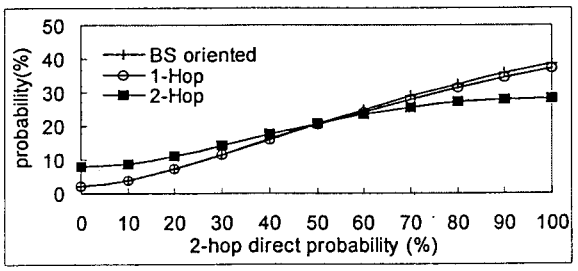

Fig. 24 Non-complete probability: 2-hop probability

4.2.3 Extent to 3-hop-direct-transmission probability

According to the above, we find the 2-hop-direct-transmission within the BS-oriented network is good. However, we can not jump to the conclusion that the 2-hop-direct-transmission is best yet. We now control the 3-hop-direct-transmission probability to involve the 3-hop-direct-transmission method. We simulate with a 100% 3-hop-direct-transmission probability. At this case, the 2-hop-direct-transmission probability is 44.44% and 1-hop-direct-transmission probability is only 11.11%. The outcomes are showed as below:

1. The number of links of Setup procedure: (see Fig 25)
   The trend is the same as Fig. 19. The direct transmission mode shave better air wave utilization than the BS-oriented scheme.

2. The total number of links in handoff procedure:
   In Fig 26, the 3-hop-direct-transmission method increases faster than others do. The reason is increasing the number of hops increasing the number of routings. So the 3-hop-direct-transmission method takes much cost for handoff when the service time of each MH is equivalent. Although it takes less number of links for each reroute, the cumulative links increases fastest.

3. New call blocking probability:
   In Fig 27, the 3-hop-direct-transmission method has smaller probability than the BS-oriented method or 1-hop-direct-transmission method, larger than 2-hop-direct-transmission method. The reason is that the 3-hop-direct-transmission method contains 1-hop-direct-transmission method and 2-hop-direct-transmission method. They consume less bandwidth by direct transmission. The 2-hop and 3-hop must take some resource for exchange data periodically, hence the probability of new call blocking is larger as the controlled probability is small.

4. The forced termination probability: (see Fig 28)
   The simulation result is based on formula (5), The curve of 3-hop-direct-transmission method seems to grow exponentially The more frequent handoff in 3-hop-direct-transmission causes more chances to be forced termination and consumes more bandwidth.

5. Non-complete probability:
   According to Fig 29, we can conclude that the 3-hop-direct-transmission method within the BS-oriented network is wireless. It increases the complexity of the network protocols without any benefits.

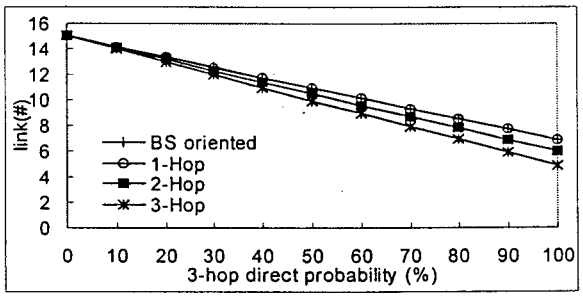

Fig.25 setup time cost: 3-hop probability

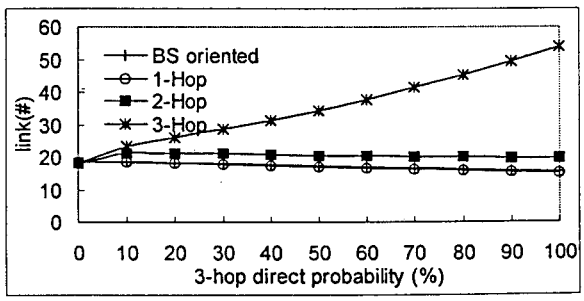

Fig.26 handoff cost (total): 3-hop probability

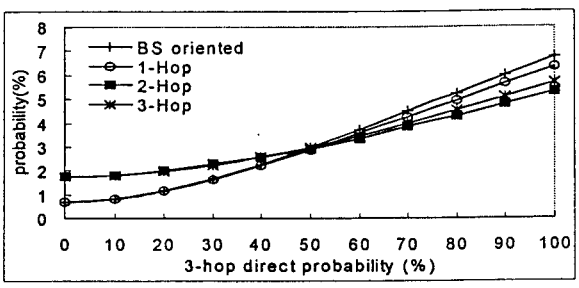

Fig. 27 New call blocking: 3-hop probability

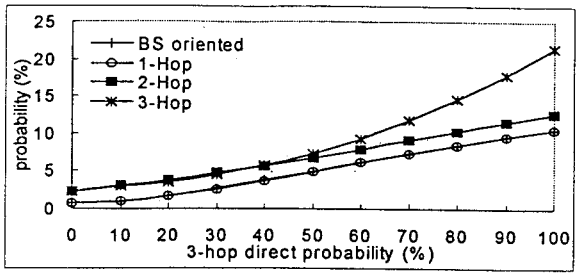

Fig. 28 forced termination: 3-hop probability

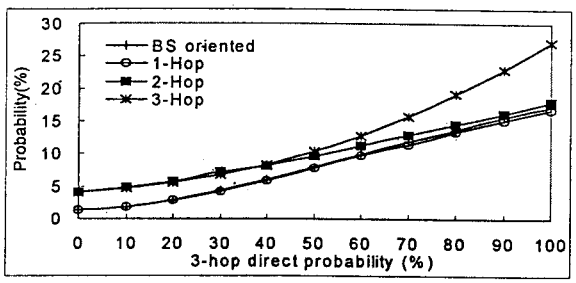

Fig.29 non-complete probability: 3-hop probability

Once the number of the direct transmission links is longer than 2-hop, the transmission air links are larger than the traditional BS-oriented. The outcomes show that the 2-hop-direct-transmission has a smaller and better non-complete probability.

5. Conclusions and The Future Work

In this paper, we introduce the operations of general BS-oriented network and ad hoc network. We compare these two operations to find the advantage of them. To avoid the problems of ad hoc network and get the advantages of it, we limit the number of hops in direct transmission within the BS-oriented. It not only increases the reliability, bandwidth utility, and saves the battery power but also solves the problems one BS failure in 2-hop-direct-transmission method and the weak connection on the ad hoc network.

Two methods are proposed: they are 1-hop-direct-transmission and 2-hop-direct-transmission within BS-oriented. According to the simulation results, the proposal methods are better than pure BS-oriented network. The 1-hop-direct-transmission within the BS-oriented network inherits the advantage of the BS-oriented. The disadvantage is smaller application area and the increase of setup cost. The 2-hop-direct-transmission has the smaller setup time, smaller new call blocking probability, and smaller non-complete probability. But for 3-hop-direct-transmission, we must have more complex neighbor database and maintain more dynamic connections. So we do not consider the 3-hop-direct-transmission within BS-oriented.

The transmission power determines the direct transmission covering range, and therefore has a direct impact on the performance of the proposal method. If the power is strong, the transmission range is large. Thus, the chance is larger for MH to transmit directly with others. However, higher interference due to large power will tend to limit the throughput. If we decrease the power, the interference is also decreased. The transmittable range also gets smaller. Hence, handoff procedure becomes more frequent and critical in this situation. Advances on power and interference avoidance technology may make the 2-hop-direct-transmission more acceptable in the future.

Reference

[1] Arup Acharya, Jun Li, and D. Raychaudhuri, "Mobile ATM: Architecture, Protocols and Implementation," *IEEE BSS*, pp.115-119, 1997.

[2] P. Bhagwat and C. E. Perkins, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," *SIGCOMM Conference Process*, pp. 234-244, Sep 1994.

[3] Imrich Chlamtac, Yuguang Fang, and Yi-Bing Lin, "Call Performance for a PCS Network," *IEEE J. Selected Area on Communication , 15(8)*: pp. 1568-1581, 1997.

[4] Ching-Chuan Chiang and Mario Gerla, "Routing in Clustered Multihop Mobile Wireless Network," *ICOIN-11 Vol. 1*, pp. 3B-1.1-3B-1.9, Jan 1997.

[5] Gopal Dommety and Malathi Veeraraghavan, "Mobile Location Management in ATM Networks," *IEEE Journal on Selected Areas in Communications. Vol. 15 no. 8*, pp. 1437-1454, Oct 1997.

[6] Rohit Dube, Cynthia D. Rais, Satish K. Tripathi, and Kuang-Yen Wang, "Signal Stability-Based Adaptive Routing (SSA) for Ad Hoc Mobile Networks," *IEEE Personal Communications, Vol. 4 No 1*, pp. 36-45, Feb 1997.

[7] David Evans, Y. Du, C Herrmann, S. N. Hulyalkar, and P.May, " Wireless ATM LAN With and Without Infrastructure," *IEEE BSS 97*, pp. 120-128.

[8] Mario Gerla and Chunhung Richard Lin, "Adaptive Clustering for Mobile Wireless Networks," *IEEE Journal on Selected Areas in Communications, VOL 15. NO. 7* pp.1265-1275, Sep 1997.

[9] Myung Sook Jin, Dong Ho Kim, Yeon Jung Kim, Ki Hyun Park, Sun Shin An, "Seamless Handoff Scheme with the Sharing Cell Structure of Mobile Computing," *ICOIN-II*, pp. 7D-3.1-7D-3.8, Jan 1997.

[10] D.B. Johnson, "Routing in Ad Hoc Networks of Mobile Hosts", Proceeding of the IEEE Workshop on Mobile Computing Systems and Application, Dec. 1994

[11] D.B. Johnson and D.A. Maltz, "Protocols for Adaptive Wireless and Mobile Networking," *IEEE Personal Communication, vol. 3, no. 1*, pp. 34-42, Feb 1996.

[12] J. Kruys, "Wireless ATM-Tales of a Marriage," *Telecommunications*, pp. 39-46, Feb 1997.

[13] Kam Lee, "Supporting Mobile Multimedia in Integrated Services Networks," *Wireless Networks 2 (1996)*, pp.205-217.

[14] Chai-Keong Toh, "Associativity-Based Routing for Ad Hoc Mobile Networks," *Wireless Personal Communications 4*, pp. 103-139, 1997.