Hybrid Wireless Network Protocols

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***Abstract*—Advances in computer and telecommunication industries have made wireless networks increasingly popular and ubiquitous. Basically, there are two types of systems for wireless networks. One is base-station (BS) oriented and the other is the ad hoc wireless network. In BS-oriented wireless networks, the mobile hosts communicate with base stations, while in the ad hoc wireless networks, the mobile hosts communicate with one another directly. The BS-oriented wireless network has better performance and is more reliable. However, the ad hoc wireless network topology is more desirable because of its low cost, plug-and-play convenience, and flexibility. Its usage of bandwidth and battery power is more efficient. The disadvantage is that the route and communication connectivity is fairly weak. Any migration by mobile hosts participating in one or more routes could make the route invalid. It incurs a lot of cost in keeping communication among them. Thus, the ad hoc wireless network is only suitable for applications in a small geographical area.**

In this paper, we propose hybrid wireless network protocols to combine the advantages of BS-oriented and ad hoc wireless networks. We allow two mobile hosts to communicate directly (one-hop direct transmission) or through another mobile host (two-hop direct transmission) within the BS-oriented networks. The hybrid protocols are more flexible, reliable, and have better performance than the traditional wireless network protocols. The simulation results show that two-hop direct-transmission has a lower noncomplete probability. If the communicating parties were always within a two-hop direct-transmission area, the rate of complete communication would improve about 20%.

***Index Terms*—Ad hoc networks, base-station (BS)-oriented networks, mobility, wireless networks.**

I. Introduction

MOBILE hosts (MHs) and wireless networking are becoming widely available and popular. Extensive work [5], [11], [13], [23], [32], [34] has been done recently in integrating these elements into traditional networks such as the asynchronous transfer mode (ATM) networks and the Internet. The rapid expansion of wireless communication technologies such as cellular network and wireless local-area network (WLAN) makes possible the support of 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 wireless ATM (WATM) [5], [23]. Motivated by the growing acceptance of ATM as a standard for broadband multimedia communication, in 1996 the ATM Forum and European Telecommunication Standard Institute started the extension of the current ATM standard to mobile WATM applications [13].

There are two basic types of structure for WLAN.

1) *Infrastructure WLAN: BS-oriented network.* Single-hop (or cellular) networks that require fixed base stations interconnected by a wired backbone.
2) *Noninfrastructure WLAN: Ad hoc WLAN.* Unlike the BS-oriented network, which has BSs providing coverage for MHs, ad hoc networks do not have any centralized administration or standard support services regularly available on the network to which the hosts may normally be connected. MHs depend on each other for communication.

The BS-oriented network is more reliable and has better 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, on a campus or in a building.

To combine their strength, we would prefer to add BSs to an ad hoc network. To save access bandwidth, battery power, and have fast connection, the MHs could use an ad hoc wireless network when communicating with each other in a small area. When the MHs move out of 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 a BS failure or weak connection under ad hoc networks. The MHs can communicate with one another in a flexible manner and freely move anywhere with seamless handoff.

There have been many techniques or concepts proposed for supporting a WLAN with and without infrastructure, such as IEEE802.11 [39], HIPERLAN [38], and ad hoc WATM LAN [13]. The standardization activities in IEEE802.11 and HIPERLAN have recognized the usefulness of the ad hoc networking mode. IEEE 802.11 enhances the ad hoc function to the MH. 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 centralized wireless control framework as the BS-oriented system but assures that MH designed for the BS-oriented system can also participate in ad hoc networking.

Adachi and Nakagawa proposed to add ad hoc capabilities to a BS-oriented mobile robot system [1]–[3]. Wijting and Prasad also mentioned the integration of mobile ad hoc networks and a cellular network [37]. However, both of them are unclear in how the ad hoc functionality is used. For example, is it limited to one

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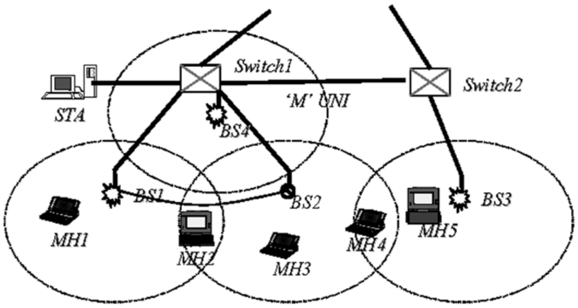

Fig. 1. BS failure problem.

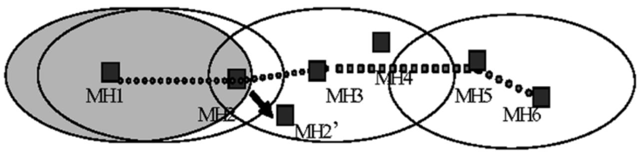

Fig. 2. Rerouting caused by mobility.

hop or unlimited? If unlimited, how is the routing done? Also the transition mechanisms and coordination between the BS mode and the ad hoc mode are not discussed. Another approach, associativity-based routing [36], also aimed to integrate the ad hoc routing into a BS-oriented WLAN environment. It takes the BS as a fixed radio port to join the ad hoc network. However, it limits the transmission mode like IEEE 802.11. When an MH receives beacons generated by other MHs, it automatically invokes ad hoc routing to support mobile-to-mobile communication. On the other hand, when it receives beacons generated by BSs, the MH knows that it has access to the wired network and hence conventional routing protocols supported by location management, registration, handoffs, etc., could be invoked. The MH in this method must be intelligent enough to decide which communication mode to use.

However, it is still not flexible enough because after transmission 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 networks. We allow two mobile hosts to communicate directly (one-hop direct transmission) or to communicate through another mobile host (two-hop direct transmission) within the BS-oriented networks. The proposed method is called "hybrid wireless network protocols." A two-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. There are, however, some changes when the transmission mode changes from direct transmission to BS-oriented or from BS-oriented to direct transmission.

The main characteristic of our hybrid protocol is to provide some ad hoc capabilities to BS-based wireless networks. There is much previous research [1]–[4], [6], [7], [14], [16]–[18], [20], [25], [26], [28]–[31], [33], [36], [37] that aimed to provide BS-like services in ad hoc networks. Among them, clustering [4], [6], [7], [14], [15], [16], [18], [26], [28]–[31] is the most studied approach. Hosts in an ad hoc network are

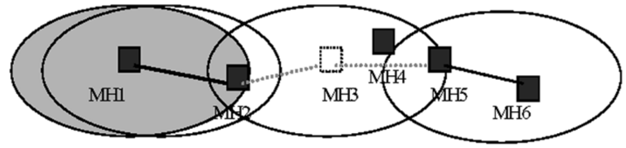

Fig. 3. Disrupted connection.

partitioned into clusters. The clustering algorithms differ in the methods used to form clusters and in response to membership changes due to hosts' mobility. In each cluster, a host acts as the cluster head. Communications within a cluster proceed as usual. However, when communicating with hosts outside one's cluster, it must be through the cluster head. Clustering makes a hierarchy of mobile hosts. Cluster heads act as base stations. Each cluster head manages the mobile hosts in its cluster. Basically they are different from our hybrid approach since there are no base stations in ad hoc networks and cluster heads are no base stations. The formation and maintenance of the clusters and their membership changes require extra processing and communication overhead, which sometimes may outweigh its potential benefits.

The rest of this paper is organized as follows. Section II discusses the weaknesses of BS-oriented wireless networks and ad hoc wireless networks. The proposed method is explained in Section III. Performance evaluations by simulations are presented in Section IV. Section V offers conclusions.

II. The Problems of BS-Oriented and Ad Hoc Networks

In the BS-oriented networks, BS manages all the MHs within the cell area and handles handoff procedures [9], [19], [22], [24], [35]. 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.

In the ad hoc networks, it is not easy to rebuild or maintain a connection [8], [10]–[12], [15], [21], [36]. When the connection is built, it will be disrupted any time one MH moves out of 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 of the coverage 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.

TABLE I
COMPARISON OF TWO WIRELESS STRUCTURES

	BS-oriented	Ad hoc network
Structure	Infrastructure wireless	Non-infrastructure wireless
Communication method	BS with Wire line (fixed)	MHs with Wireless (dynamic)
Suitable area	Any	Small
Key function	Handoff & location management	Routing discovery & maintenance
Database overhead	Have Home location register and Visitor location register in BS	Each MH maintains the databases
Advantage	·Reliable ·Connect to the wired line ·The MH is simple ·The connection is robust ·Higher bandwidth utility	·Low cost ·Plug and Play ·Flexibility ·Minimal human interaction requirements ·The available bandwidth is doubled with direct transmission
Disadvantage	·The infrastructure must exist ·Handle handoff ·Ping-Pong effect ·Human interaction requirements	·Connectivity is fairly weak ·Unreliable ·Use most of the bandwidth for routing maintenance ·Limited size
Problem	·BS failure ·Handoff procedure ·New call blocking ·Forced termination	·The connection is erased by mobility ·Hidden terminal problem ·Frequent reroutes ·Many "links" between routers seen by the routing algorithm may be redundant ·Periodically sending routing update wastes network bandwidth. Wastes battery power ·New call blocking ·Forced termination

According to the above discussions, we list the advantages and disadvantages of the two structures in Table I.

The main characteristics for an ad hoc network are rapid deployment and dynamic reconfiguration. When the BS-oriented network is not available, such as in battlefield communications and search and rescue operations, the ad hoc network provides the only feasible means for ground communications and information accesses. The dynamic feature in the ad hoc network leads to the problem of keeping track of the topology connectivity. To combine the advantages of the ad hoc networks with those of the BS-oriented networks, we propose a hybrid system protocol. To alleviate the problems caused by the multihop routing problems, we limit the number of hops of direct transmission to two within the BS-oriented network.

The proposed method is easy to implement. The MHs could communicate with each other over the wireless media, without any support from the infrastructure network components within the signal transmission range. But when the transmission range is less than the distance between the two MHs, we could change back to the BS-oriented systems. MH is able to operate in both ad hoc and BS-oriented WLAN environments.

III. THE PROPOSED METHODS

We propose two different methods: one-hop direct transmission within BS-oriented and two-hop direct transmission within BS-oriented. The first method is simple and controlled by the signal strength. The second method should include the data forwarding and implementation of routing tables.

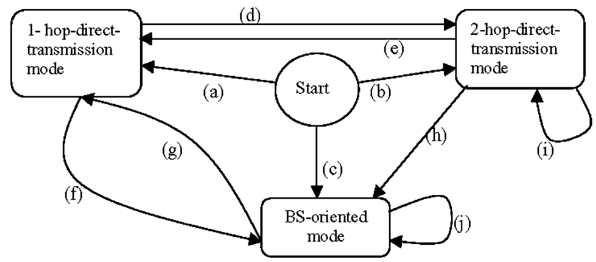

Fig. 4. Transition diagram for transmission mode.

A. Control Messages and State Transition Diagrams

To integrate the BS-oriented method and the direct transmission method, we define some control messages.

1) ACK/ACCEPT/REJECT: used to indicate the acknowledgment, acceptance, or denial of connection or handoff request.
2) CHANGE: used by MH to inform the sender to initiate the handoff procedure.
3) DIRECT: used by MH to inform BS that the transmission is in direct transmission mode.
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.
6) TEARDOWN: used for switching from BS-oriented handoff to direct transmission. It will let BS release the channel and buffer.
7) AGENT: used by the MH whose BS fails to accept another MH acting as a surrogate for transmission.
8) BELONG: used by a surrogate MH to accept another MH's WHOSE-BS-ALIVE request.
9) WHOSE-BS-ALIVE: used by the MH whose BS failed to find a surrogate MH.

Since a mobile host may be in BS-oriented mode, one-hop direct-transmission mode, or two-hop direct-transmission mode, it is important that we understand the timing for mode transition. Fig. 4 shows the state transition diagram.

The meaning and timing of each transition are explained below.

a) The receiver can receive the sender's signal directly.
b) The receiver is a neighbor of a neighbor of the sender.
c) Neither case a) nor b).
d) The receiver can no longer hear the sender's signal. However, a neighbor of the sender can communicate with the receiver directly.
e) The receiver discovers that it can hear the sender's signal directly.
f) The receiver can no longer hear the sender's signal, and none of the sender's neighbors can communicate directly with the receiver.
g) The receiver discovers that it can hear the sender's signal directly.

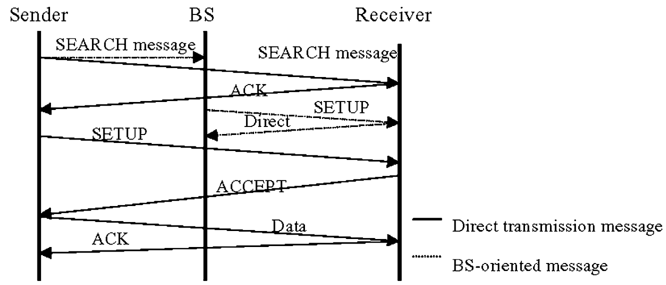

Fig. 5. Using one-hop direct-transmission mode.

h) No neighbors of the sender can communicate with the receiver directly.

i) The sender's original relay neighbor fails. However, the sender can find another neighbor that can communicate with the receiver directly.

j) The handoff from one BS to another.

In Fig. 4, we note the following two points.

1) When a mobile host starts communication, it could be in any mode depending on the position of the receiving mobile host.
2) The transition from the BS-oriented mode to two-hop direct-transmission mode is not possible because the communicating party cannot know that a third mobile host exists and is within range.

B. Direct Transmission

Direct transmission defines the situation where two mobile hosts communicate directly or use a third mobile host as a relay without the help of base stations. We consider the location management and handoff procedures when the MH moves around. These functions are almost the same as the traditional ones. However, we must decide whether one-hop direct transmission, two-hop direct transmission, or BS-oriented transmission method should be used. When the sender broadcasts the connection request message, both the BS and the 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 one-hop direct-transmission method. (If we allow two-hop direct transmission, each receiving mobile host must check its neighbor database to see if the destination is currently a neighbor of itself.) Otherwise, the BS would be used for connection. When the destination moves out of the covering area, the BS would have to take over. On the other hand, when the MH moves into the covering range, the receiver has the option to stop going through the BS and changes to one-hop direct transmission.

C. The Protocol for One-Hop Direct Transmission

For one-hop direct-transmission mode, each case of protocol operations is described in more detail as follows.

1) One-Hop Direct-Transmission Mode (Fig. 5):

1) Sender broadcasts a SEARCH message. Every node in the signal covering range (including the BS) would receive the message.
2) If the receiver is within the range, it receives the message and finds out the destination is itself. It will respond with the message ACK back to the sender.
3) At the same time, the BS would also receive the SEARCH message. It locates the MH and sends the SETUP message to the destination. For direct transmission, the destination receives the SETUP message and sends the DIRECT message to BS. Otherwise, it sends an ACCEPT message to the BS, and the communication will be in BS-oriented mode.
4) The sender continues transmitting directly until the MH moves out of the covering area.

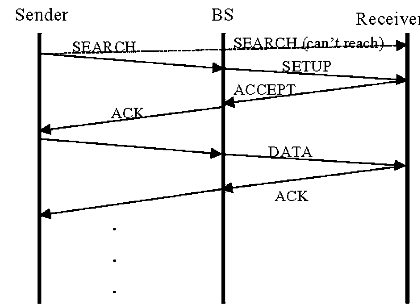

Fig. 6. Using the BS-oriented mode.

2) BS-Oriented Mode (Fig. 6):

1) Sender broadcasts a SEARCH message. If the receiver were out of the covering range, it would not receive the message. (It is possible that two-hop direct-transmissio mode can be used. This will be explained in Section III-D2.)
2) However, the BS of the sender would always receive the SEARCH message. It queries the receiver's position and sends the SETUP message to the destination.
3) When the destination receives the SETUP message, it sends an ACCEPT message to the BS.
4) The communication continues by BS-oriented mode until the distance between the two MHs is close enough and the receiver wants to change to direct transmission mode.

3) Handoff—Out of Direct Transmission Range: In direct transmission mode, when the destination detects that the strength of the signal is less than an acceptable value, handoff should be executed. The procedures are described as follows.

1) The destination sends the CHANGE message to its sender.
2) As the sender receives the CHANGE request, it will send out the SEARCH message again. Then a BS-oriented mode will be used as in Section III-C2, or a two-hop direct-transmission mode will be used, as explained later in Section III-D2.

4) Handoff—BS to One-Hop Direct Transmission (Fig. 7): If the receiver detects that it is within the covering region of the sender's signal and the signal is strong enough, it has the option of switching from the BS-oriented mode to one-hop direct-transmission mode. Each step is described below.

1) The receiver sends the CHANGE request to the sender.

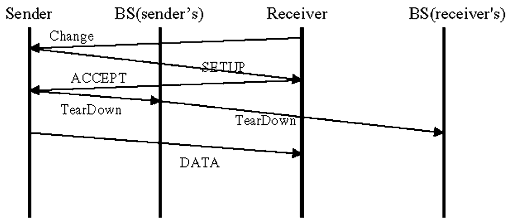

Fig. 7. Flowchart: BS-oriented handoff to one-hop direct transmission.

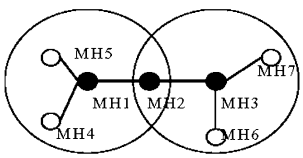

Fig. 8. Two-hop direct-transmission zone.

TABLE II
THE NEIGHBOR DATABASE FOR MH1 IN FIG. 9

Neighbor ID	BS-down
MH2	False
MH4	False
MH5	False

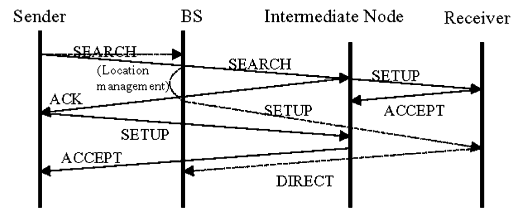

Fig. 9. Two-hop direct-transmission mode.

2) The sender sends the SEARCH message out. Then the one-hop direct-transmission will be established through the steps in Section III-C1.
3) After the sender receives the ACCEPT message from the receiver, it sends a TearDown message to the BS and breaks the connection along the path.

D. Protocols for Two-Hop Direct-Transmission Mode

Two-hop direct-transmission mode will cover a wider area than one-hop direct-transmission mode. It allows two mobile hosts to communicate through a third mobile host acting as a relay. Therefore, each mobile host must implement a neighbor database to record its current neighbors. (A neighbor of a mobile host is another mobile host that can be connected directly with radio waves and without the help of base stations.) Furthermore, we must handle the case when the two-hop direct-transmission connection is disrupted because of mobility, for example, the relay MH moves out of range or the destination moves out of range.

With one-hop or two-hop direct transmission, the system reliability is increased since some mobile hosts can still communicate with others even if their base stations fail. However, why do we limit the number of hops in direct transmission to two? What are the advantages of two-hop direct transmission compared to three hops or more? The reasons are described as follows.

1) The routing will become complicated in three-hop or more direct transmission. In multihop direct communications, handling many routing paths wastes the bandwidth in exchanging routing information, time stamps, avoiding routing update loop, and so on.
2) Problems of ad hoc networks, such as routing and connections maintenance, would be more manageable.
3) If we allow three-hop direct transmission, the number of links in the air (at least three) not involving routing exchange would be larger than the BS-oriented mode (always two). In the long run, the battery power consumption would be more than the BS-oriented mode.

1) The Neighbor Database: In two-hop direct-transmission mode, each MH will maintain a simple database (see Table II) to store the information of neighboring MHs within its radio covering area. Each mobile host must broadcast periodically to inform the neighboring MHs of its related information. For example, the neighbor database of MH1 in Fig. 8 is shown in Table II.

In Table II, the BS-down field indicates whether or not the neighboring mobile host can detect a nearby base station. A value of *True* means that the mobile host cannot connect to a base station.

2) Two-Hop Direct-Transmission Mode (Fig. 9): This situation applies when the sender and destination are both within an intermediate's coverage area. The sender transmits the data to the destination through an intermediate MH. The connection setup procedures are as follows.

2) If an MH is within the transmission range, it receives the sender's message. There are two cases.
   a) When the receiver finds the destination is itself, it sends the message ACCEPT back to the sender. The connection will be the one-hop direct transmission.
   b) If the destination is not itself, the mobile host checks the neighbor database. If the destination is in the database, it forwards the SETUP message to make connection to the destination. After the destination accepts the connection setup, it sends ACCEPT back to the sender.
3) If the destination receives many copies of SETUP, it only accepts the first one. The redundant messages will be discarded. The other candidate intermediate nodes will give up after timeout.
4) At the same time, the BS would receive the SEARCH message. It queries the MH and sends the SETUP message to the destination. For direct transmission, the destination receives the SETUP message and sends the DIRECT message to its BS. Otherwise, the destination would accept the connection from the base station.
5) The communication will continue transmitting directly until the transmission path is broken.

3) Handoff—Two-Hop Direct-Transmission Mode to Two-Hop Direct-Transmission Mode, One-Hop Direction-Transmission Mode, or BS-Oriented Mode: If the destination

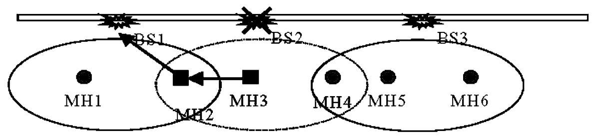

Fig. 10. The BS failure problem.

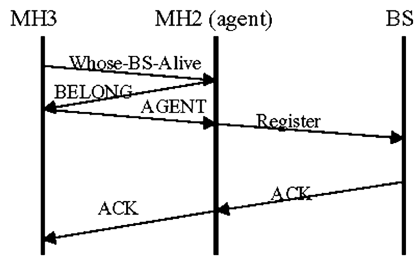

Fig. 11. MH whose BS failed uses neighbor as an agent.

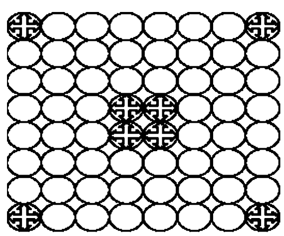

Fig. 12. The WLAN topology considered in the simulation.

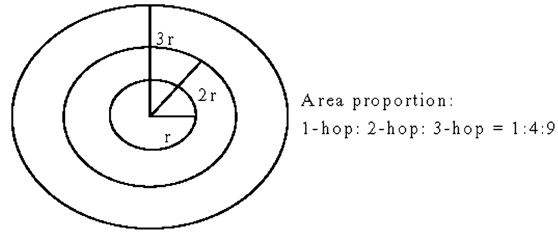

Fig. 13. Area proportion.

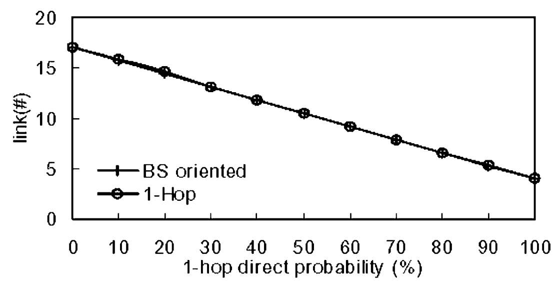

Fig. 14. The cost of setup: one-hop probability.

or the intermediate node finds that the strength of the signal is less than a critical value, the handoff procedure is requested and executed at this time. The system will try to find another direct transmission path. If a direct transmission path is not found, the BS-oriented mode will take over. The handoff procedures are listed as follows.

2) The destination or intermediate node sends the CHANGE message to the sender for changing connection.
3) As the sender received the CHANGE request, it reinitiates the connection by sending out SEARCH. The next several steps are the same as in the initial connection setup in Section III-D2.

4) How to Solve the Problem of BS Failure: Our method is also robust against BS failure in the middle of a connection. In Fig. 10, when MH3 finds that its BS (BS2) failed, it performs the following steps until its BS is alive again. (See Fig. 11 for message flow.)

2) MH3 broadcasts the Whose-BS-Alive message to the neighbors.
3) If one MH, say, MH2, receives the message and its BS is still alive, it records the sender ID and sends the BELONG message back to the sender.
4) MH3 receives the BELONG message and records MH2's ID. Then it sends the AGENT message to MH2.
5) After the agent (MH2) receives the AGENT message, it represents MH3 to register its location to its BS (BS1).
6) MH2 will now relay the information to and from MH3. When MH2 or MH3 is leaving the other's covering area, MH3 would give up the current agent and repeat steps 1)–4) to find another agent. MH2 then removes the registration of MH3 from BS1.

IV. Performance Evaluation

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:

2) failure rate, e.g., new call blocking, forced termination, and so on;
3) cost, e.g., average handoff cost, number of communication links used, and so on.

A. 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. Define an $8 * 8$ array as the cell model (see Fig. 12). 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 handoff is the most difficult to implement. 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 the nonprioritized 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:

2) new request arrival time: exponential (0.5);
3) service time: exponential (25.0);

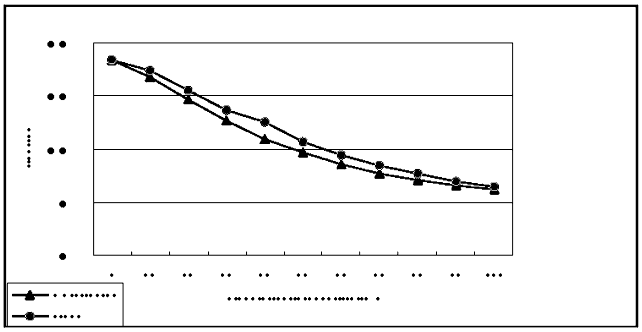

Fig. 15. The total cost of handoff: one-hop probability.

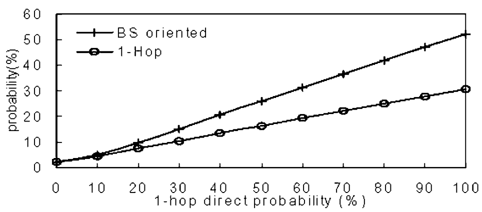

Fig. 16. New call blocking: one-hop probability.

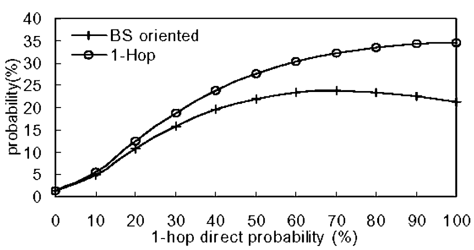

Fig. 17. Forced termination: one-hop probability.

4) cell resident time: exponential (12.0) (BS-oriented):
   a) exponential (6.0) (one-hop direct transmission);
   b) exponential (3.0) (two-hop direct transmission);
   c) exponential (1.5) (3-hop-direct transmission);
5) N: number of new calls;
6) Nh: number of handoffs;
7) Nb: number of new calls blocking;
8) Nf: number of forced termination;
9) Nc: number of completion calls.

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

$$\text{one-hop direct-transmission probability} = \frac{\text{three-hop direct-transmission probability}}{9} \quad (1)$$

$$\text{two-hop direct-transmission probability} = \text{one-hop direct-transmission probability} * 4. \quad (2)$$

The new call blocking probability (Pb) is computed as

$$Pb = \frac{Nb}{N}[27] \quad (3)$$

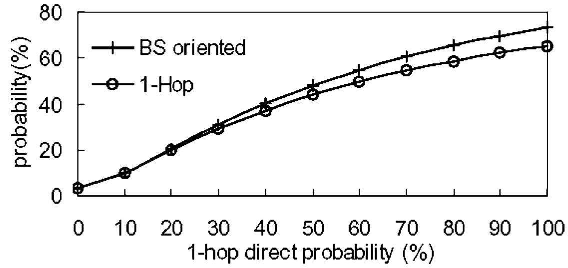

Fig. 18. Noncomplete probability: one-hop probability.

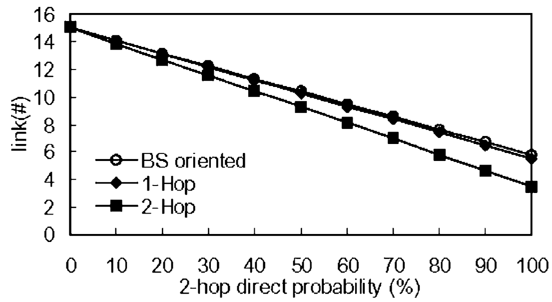

Fig. 19. The cost of setup: two-hop probability.

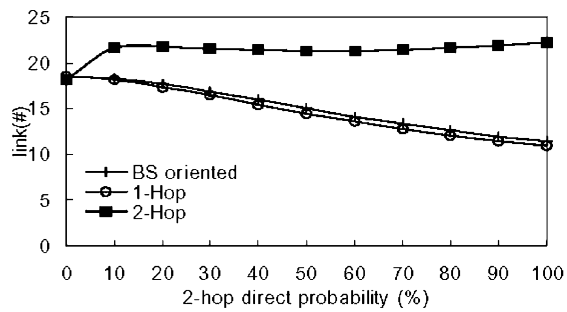

Fig. 20. The total cost of handoff: two-hop probability.

and the formula for the forced termination $(Pf1)$ is

$$Pf1 = \frac{Nf}{Nh}[27] \quad (4)$$

$$Pf2 = \frac{Nf}{N}. \quad (5)$$

These two formulas are different in the denominator. Equation (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 the total number of MHs in (5); it means the average probability of forced termination of each MH.

The third one is the probability of noncomplete (Pnc)

$$\text{Pnc} = \frac{(Nf + Nb)}{(Nf + Nb + Nc)}[27]. \quad (6)$$

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

B. Simulation Results

In this section, we test the performance of the proposed hybrid protocols by simulations. Define the two (three)-hop-direct

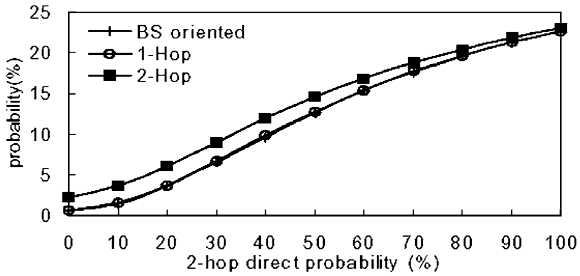

Fig. 21. Forced termination: two-hop probability.

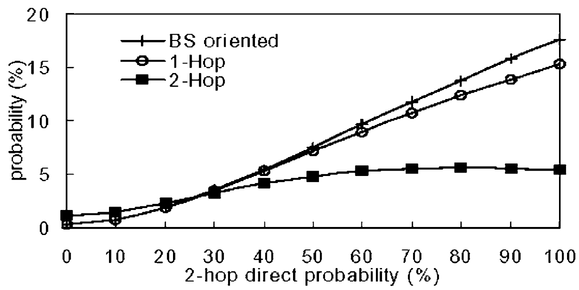

Fig. 22. Average forced termination: two-hop probability.

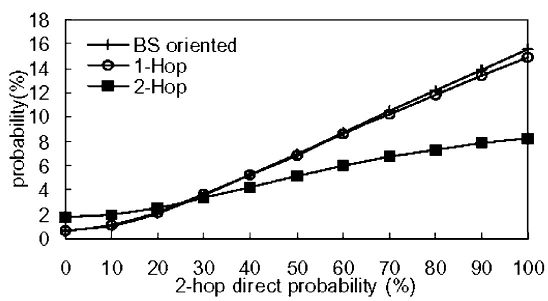

Fig. 23. The new call blocking: two-hop probability.

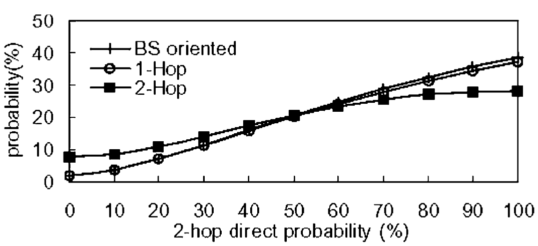

Fig. 24. Noncomplete probability: two-hop probability.

probability as the probability that, in mobile communications, the sender and the receiver are within the two (three)-hop-direct-transmission range. For example, if the two-hop direct probability is large, then the sender and the receiver are probably communicating using the two-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.

1) Control the One-Hop Direct-Transmission Probability: By controlling the one-hop direct-transmission probability, we try to find out whether the one-hop direct-transmission method is better than BS-oriented. The results are shown as follows.

2) The number of links of the setup procedure (see Fig. 14). The two curves overlap on the number of setup links because the connection setup procedure for one-hop direct-transmission method is almost the same as a connection setup to a base station.
3) The total number of links in handoff procedure (see 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.
4) New call blocking probability (see Fig. 16). For each MH using one-hop direct-transmission method, there is smaller probability of being blocked because it will not suffer from unavailable channels at the base stations.
5) The forced termination probability (Fig. 17). Frequent handoff in one-hop direct-transmission mode makes the forced termination probability worse.
6) Noncomplete probability (see Fig. 18). The noncomplete probability combines new call blocking probability and forced termination probability. It is a good performance measure. From the trend of the curve, the one-hop direct-transmission method is better than the BS-oriented method.

2) Control the Two-Hop Direct-Transmission Probability: By controlling the two-hop direct-transmission probability, we try to find out whether the two-hop direct transmission is better than one-hop direct transmission or BS-oriented. The results are shown as follows.

2) The number of links of the setup procedure (see Fig. 19). The direct transmission mode should have better air wave link utilization than BS-oriented. As the two-hop direct-transmission probability increases, the number of links decreases.
3) The total number of links in handoff procedure (see Fig. 20). 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.
4) The forced termination probability. We compare (4) and (5) in Figs. 21 and 22. In Fig. 21, the forced termination probability of direct-transmission and BS-oriented mode 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 (5), the two-hop direct transmission has smaller forced termination probability.
5) New call blocking probability (see Fig. 23). According to the assumption, once a new request cannot get the bandwidth, it will be blocked. As each MH uses the two-hop direct-transmission method, it has less probability of blocking than the frequent handoff. When it has more chance to transmit directly, it saves more bandwidth for others to use. Therefore, when the probability of communication within two-hop is larger than 25%, the two-hop direct transmission will have smaller new call blocking probability.

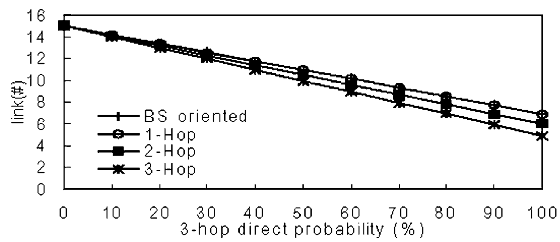

Fig. 25. Setup time cost: three-hop probability.

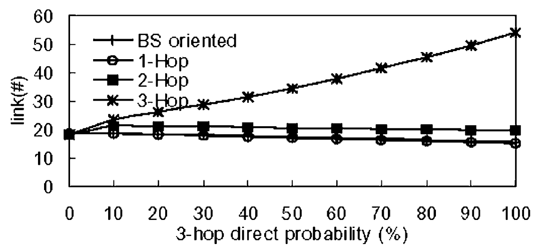

Fig. 26. Handoff cost (total): three-hop probability.

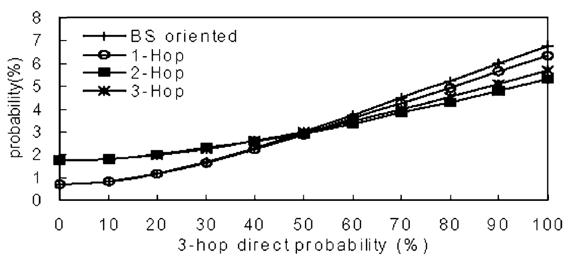

Fig. 27. New call blocking: three-hop probability.

6) Noncomplete probability (see Fig. 24). From the trend of the curve, the two-hop direct-transmission method increases the slowest. The one-hop direct-transmission method is better than the BS-oriented method.

3) Extension to Three-Hop Direct-Transmission Probability: According to the above, we find that the two-hop direct transmission within the BS-oriented network is good. However, we cannot jump to the conclusion that two-hop direct transmission is the best yet. We now simulate the three-hop direct-transmission method. We simulate with a 100% three-hop direct-transmission probability. In this case, the two-hop direct-transmission probability is 44.44% and one-hop direct-transmission probability is only 11.11%. The outcomes are shown below.

2) The number of links of the setup procedure (see Fig. 25). The trend is the same as Fig. 19. The direct transmission mode has better air wave utilization than the BS-oriented scheme.
3) The total number of links in the handoff procedure. In Fig. 26, the three-hop direct-transmission method increases faster than others do. The reason is that increasing the number of hops increases the number of routings. So the three-hop direct-transmission method incurs a lot of overhead for handoff.
4) New call blocking probability. In Fig. 27, the three-hop direct-transmission method has smaller probability than the BS-oriented method or one-hop direct-transmission method but larger than the two-hop direct-transmission method. The reason is that the three-hop direct-transmission method includes one-hop direct-transmission method and two-hop direct-transmission method. They consume less bandwidth by direct transmission. The two-hop and three-hop must use some resources for exchange data periodically; hence the probability of new call blocking is larger when the probability is small.

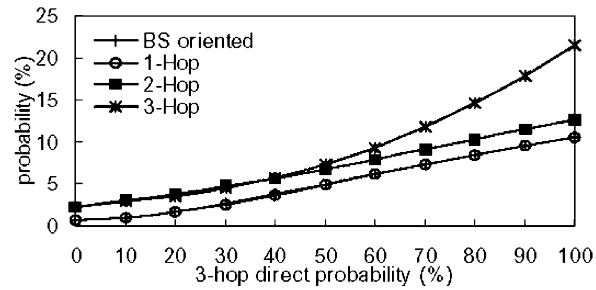

Fig. 28. Forced termination: three-hop probability.

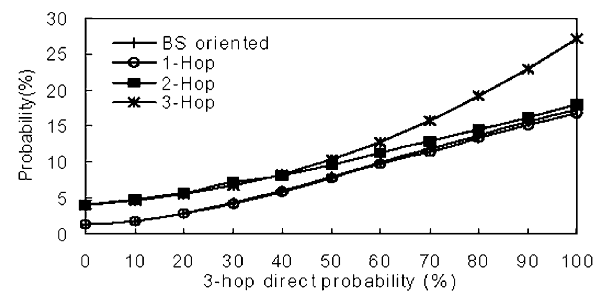

Fig. 29. Noncomplete probability: three-hop probability.

5) The forced termination probability (see Fig. 28). The simulation result is based on (5). The curve of the three-hop direct-transmission method seems to grow exponentially. The more frequent handoff in three-hop direct transmission forces it to terminate more frequently.
6) Noncomplete probability. According to Fig. 29, we can conclude that the three-hop direct-transmission method within the BS-oriented network is useless. It increases the complexity of the network protocols without any benefits.

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

V. CONCLUSION AND FUTURE WORK

In this paper, we introduce the operations of general BS-oriented networks and ad hoc networks. We compare these two infrastructures for advantages and disadvantages. To combine their advantages and avoid the problems of ad hoc networks, we allow direct transmissions between mobile hosts in BS-oriented networks. However, we limit the direct transmissions to at most two hops such that the protocol complexity would not be increased too much. The proposed system is more reliable, increases bandwidth utility, saves battery power, and is more fault-tolerant to BS failures.

According to the simulation results, the proposal methods are better than pure BS-oriented networks. The one-hop direct-transmission mode inherits the advantage of the BS-oriented networks. The disadvantage is its smaller application area and the slight increase in setup cost. The two-hop direct-transmission mode has smaller new call blocking probability and smaller noncomplete probability.

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 greater for MHs to transmit directly with others. However, more interference due to large power will tend to limit the throughput. If we decrease the power, the interference also decreases, as does the transmission range. As a result, handoff becomes more frequent and critical in this situation. Therefore, future advances on power and interference avoidance technology may make the two-hop direct-transmission mode more beneficial.

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