Resource Consumption and Mobility-based Adaptive Management for Heterogeneous Wireless Networks

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Abstract: An adaptive management for heterogeneous wireless network is proposed to deal with the handoff process and route selection. It consists of a type selection process, a routing discovery process, and a handoff and maintenance process. Furthermore, the routing discovery process includes route discovery phase and route selection phase. Via hybrid wireless networks, one can serve 50% more users than the homogeneous ad hoc network. The proposed type selection process can decide and select the proper type of handoff process based on mobility to reduce the total cost from 9.16% to 98.44%. The proposed routing discovery process can reduce block rate about 12~17% and the transmission time about 5% to 22%.

Key-Words: Heterogeneous wireless network, resource consumption, mobility, network management.

1 Introduction
To establish communications, most of the existed wireless systems utilize an infrastructure such as a base-station (BS) and an access point. Another form of wireless communication without using any infrastructure is mobile ad hoc networks (MANET).

To maintain a communication in the cellular system or MANET [4], there are two processes used to make the handoff in time: 1) proactive resource reservation protocol; 2) reactive mobility and motion estimation protocol. Since there are two types of routing protocols, to dynamically select a suitable type of protocols costs under different resource consumption such as bandwidth, power, computing, etc., to reduce the cost becomes an important issue.

1.1. The Proactive Type Protocol in Cellular System and MANET
Rajagopal et al. [1] suggested the GPS based bandwidth reservation scheme to improve the adaptive bandwidth reservation scheme. Kuo et al.[2] reserves most bandwidths of the base station with a higher handoff probability of a host based upon the host’s mobility. These handoff algorithms execute the resource reservation proactively regardless possible implementation in the handoff process.

In MANET, each mobile device periodically broadcasts the information, including mobility, direction, bandwidth supported, efficiency, and flow, to other mobile devices in its neighborhood. Relying on this concept, Royer and Toh [4] developed an algorithm that emphasizes on the number of intermediate nodes used between the source node and destination node for the shortest path searching.

However, the information of neighborhood and the environment of network are not static. To excessively reserve resource and bandwidth for handoff in advance is quite a waste. In addition, to periodically refresh the information in MANET also costs time and resource.

1.2. The Reactive Type Protocol in Cellular System and MANET
Yu et al.[3] developed an algorithm to consider the current location of a mobile host and its moving direction. Then, only the possible base stations are required to reserve the resource. However, if the handoff can not be made before the node approaches the next BS, the communication will be blocked.

In MANET, to reflect dynamic behaviors of an ad hoc network, Dynamic source routing [5], developed by Broch, Johnson and Maltz, is an algorithm that searches a routing path without keeping a table in advance. The source node broadcasts a routing request (RREQ) message to its neighbor nodes only when the route is desired. Dube [6] selected intermediate mobile devices with an on-demand signal stability.

However, the mobility, memory, and power consumption of each mobile device are different and limited. Using the reactive type protocol may cause resource consumption and higher traffic load to broadcast the RREQ message comparing to the proactive type protocol which can directly find the routing path.
1.3. Heterogeneous Wireless Network

Many researchers have brought up the project of 4G or called B3G which integrates all kinds of nowadays heterogeneous networks [8]. However, the project also faces many research challenges and issues, such as handoff, pricing and billing, location coordination, and so on [7]. Furthermore, most researches offer only conceptual models or provisions toward the 4G [8]. In a heterogeneous wireless network, the resource requirements, handoff strategy, and routing protocols are different from each simplex network. Moreover, the balancing of the multi-cells in cellular system and the selection of multiple routing paths in wireless networks also affect the performance.

1.4. Summary

Within the heterogeneous wireless network, the proposed algorithm is able to dynamically select the proper type of protocols for a mobile device when searching for a new communication route or deciding a handoff process according to the current network environment and costs of each type of protocol. The major contributions of the proposed adaptive management for heterogeneous wireless network (AMHN) are:

(1) Deal with the mobile devices with different mobility.
(2) Save resources, and better cost saving.
(3) Take user mobility, bandwidth, power consumption, route selections, communication type, and network types into consideration, as a result, the total cost caused from the network can be reduced.

The rest of the paper is organized as follows: Section 2 describes the proposed algorithm. Analyses and results are presented in Section 3. Finally, conclusion is drawn in Section 4.

2 The Proposed Algorithm

For the hybrid wireless network, assume that each mobile hosts equipped with the cellular interface and ad hoc interface. In cellular systems, a base station can provide large-scale coverage range of transmission. In contrast, devices use mobile ad hoc network following IEEE802.11 standard obtains high transmission rate.

The overall architecture of the proposed AMHN is illustrated in Fig. 1. The routing discovery process for a new communication is based on result of the type selection process. The result of the type selection process is also used in handoff and maintenance process for a handoff communication. The detailed flow of each block will be presented in the following sections.

2.1 Type Selection Process

Fig. 1. The overall architecture of adaptive management for heterogeneous wireless network.

Suppose that the current state of wireless environment can be detected by the mobile devices and the base stations. Then, the proposed type selection process can make a decision to select a suitable type routing protocol.

Within the network environment, the communication range of a device, which may be a mobile device or a base station, is denoted with a radius \( r \). The total number of devices, \( \alpha \), surrounding the center device within the radius \( r \) is countable. Suppose that the distance between a device and the center is \( s \), and the rest distance of a device to move over this circle is \( x \). As a devices moves, no matter it is in a cellular system or in the mobile ad hoc network, there exists a relative velocity between each device and the center host. Suppose that the moving velocity, \( v \), of the \( i \)th mobile host within the center device’s coverage is \( v_i \) and the average velocity of all mobile devices is \( v_{avg} \) defined as:

\[
v_{avg} = \frac{1}{\alpha} \sum_{i=1}^{\alpha} v_i
\]

2.1.1 Cost of Proactive Type Protocol

When a center device implements a proactive type routing protocol, this device needs to maintain an information table. To acquire and record information from other devices, it takes up power consumption and memory. Suppose that the memory cost to record the information of one device is \( \sigma \). Then the center device has to spend \( \alpha \times \sigma \) cost to record information of the total number \( \alpha \) of all other neighboring mobile hosts. Before the network state changes, the information table should be updated to keep the immediate information. In other words, the information table should be refreshed before a mobile host leaves this communication coverage. Suppose that the probability density function of \( v \) is \( f(v) \) and \( T_x \) is the sojourn time. Then, the probability density function of \( T_x \) can be defined as \( f_{x}(t) \).

The expected updating time \( T \) as:

\[
T = \int_{v_{avg}}^{\infty} x f(v) dv = \frac{v_{avg}}{\alpha \sigma}
\]

Additionally, to refresh the information, all the mobile hosts inside the communication coverage have to consume power to exchange the information for each
other. Suppose that the cost of \( i^{th} \) device to broadcast information is \( P_i \). The average cost of periodical information updating is defined as:

\[
\frac{1}{T} \sum_{i=1}^{\infty} P_i + a \sigma
\]

(3)

### 2.1.2 Cost of Reactive Type Protocol

In opposition to proactive type protocol, the reactive type protocol only broadcasts the route request message when desired. Suppose that the center mobile device broadcasts the RREQ message and the power consumption is denoted as \( P_c \). To re-broadcast the RREQ message, the total consumption of all other nodes is denoted as \( \sum_{i=1}^{\infty} P_i \), where \( P_i \) denotes the power consumption of \( i^{th} \) mobile device. According to the existing routing algorithms, the route request message is sent disjointedly to decrease the traffic load. If an RREQ message is ever received, this RREQ message will be discarded.

Therefore, if the center device attempts to establish a communication with another device (destination node) within its communication range, the cost to broadcast the route request message within its communication coverage is:

\[
P_c + (\sum_{i=1}^{\infty} P_i + P_o) = P_c + \sum_{i=1}^{\infty} P_i
\]

where \( P_o \) denotes the power consumption of the destination node to send the RREQ reply message (RREP). The function \( \sum P_i - P_o \) indicates that the destination node needs not to re-broadcast the RREQ to itself. In addition, the power consumption depends on the distance. The free space propagation model is used to predict received signal strength. Suppose that the distance between the transmitter and the receiver is \( d \).

The strength of the signal received can be defined as follows:

\[
P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \geq P_t \Rightarrow P_t \geq \frac{(4\pi)^2 d^2 L P_r}{G_t G_r \lambda^2} \propto d^{-2}
\]

(5)

where \( P_t \) is the transmitted power, \( P_r(d) \) is the received power, \( G_t \) is the transmitter antenna gain, \( G_r \) is the receiver antenna gain, \( L \) is the system loss factor, and \( \lambda \) is the wavelength in meters. Eq. (5) means that to guarantee the received power higher than a threshold \( P_r \), the transmitted power should be ample. It is evident that the power cost escalates when the distance between mobile host and center device increases.

According to Eqs. (3) and (4), since there are two types of routing protocols that each takes different costs, how to select a suitable one that corresponds to the dynamic hybrid wireless network is important.

In the cellular system, the type of handoff process has to be decided. Suppose that a center device pays the cost to gain and maintain the information table periodically. In addition, suppose that a handoff process should be executed in a time period, \( t_h \). According to Eq. (2), the expected leaving time of \( i^{th} \) mobile device after a timespan \( t \) can be defined as:

\[
t_i = \frac{\ln(1 - \nu_i t)}{\nu_i}
\]

(6)

If the expected leaving time is shorter than handoff processing time, the communication will be blocked before the handoff being completed. Therefore, the following criterion should be guaranteed as \( t_i \leq t_h \).

Suppose the cost for bandwidth pre-reservation is \( C_{BR} \) and the cost for re-transmitting data packets is \( C_{PL} \). Then, we define a tuning parameter \( \beta \), which depends on the ratio of \( C_{BR} \) and \( C_{PL} \), such that the cost for different environments can be minimized. We define \( \alpha _x \) as the total number of mobile devices using reactive type and \( \alpha _p \) as the total number of mobile devices using proactive type. The rule to decide which type of protocol to use is given as follows:

If \( v_i \beta \nu_{avg} > 0 \), proactive type handoff process is selected, else, reactive type handoff process is selected.

(7)

After that, the total cost function of handoff process after type decision rule can be defined as follows:

\[
f(v, \), \beta, \nu_{avg} \alpha _x C_{BR} + \alpha _p C_{PL} \]

(8)

In the mobile ad hoc network, all the mobile hosts must broadcast the information from themselves to others. According to Eqs. (3) and (4), the function used in MANET can be written as follows:

\[
f_{Manet}(T) = (P_c + \sum P_i - \frac{1}{T} \sum P_i + a \sigma)
\]

(9)

where \( P_S \) indicates the power consumption of a source node. Suppose the communication required ratio to communicate with the destination node in the coverage within time period \( t \) is denoted as \( \mu \). In addition, since there are two types of routing protocols, switching back and forth between the two protocols also consumes resources. Hence, after the time period \( t \), the cost decision function can be rewritten as:

\[
f_{Manet}(\nu ) = (\mu x + a ) \times (P_c + \sum P_i - (1/ T) \sum P_i + a \sigma)
\]

(10)

where \( 0 \leq \mu \leq 1 \).

Similarly, for MANET, if \( f_{Manet}(\nu ) \) is larger than zero, the proactive type protocol is used, otherwise, the reactive type routing protocol is used.

### 2.2 Routing Discovery Process

The flowchart of the routing discovery process is illustrated in Fig. 2. After the type selection process, the base station informs the selection result to the host and starts the routing discovery process. First, the base station checks the destination in visitor location register or home location register for the host to classify the communication as the specific source and destination relation traffic type or a static service node connected to a fixed network called “Internet Access.” These two
types of traffic load are used in the hybrid wireless network environment.

2.2.1 Internet Access
For this type of traffic load, the mobile host sends the RREQ messages through the base station to the Internet server. The base station runs the capacity test to check if base station has enough bandwidth to support this request or not and sends the Acknowledge message (ACK) backward to the mobile host. If the capacity test succeeds, it means that the base station can serve the mobile device and the routing path can be established. Otherwise, the request is blocked.

2.2.2 Route Discovery Phase
If the communication request is identified as specific source and destination type traffic, the route discovery phase starts.

During route discovery phase, the base station is assumed to act as a mobile host when joining the routing discovery. However, the resource support, such as bandwidth, power, and computing ability, between a base station and a mobile host are different. Hence, when a base station receives the RREQ message, the base station has to check the visitor location register to avoid re-flooding messages to reachable mobile hosts wasting the uplink bandwidth. If the destination is reachable within this base station, the base station sends RREQ message to the destination node and appends its information such as bandwidth, etc. If the destination is not reachable, the base station checks the home location register to find the registered users in other base stations. Finally, the base station appends its information and forwards RREQ messages to reachable base station through the fixed network to find the destination mobile device.

If the host is a mobile host, it checks the ID of the destination recorded in RREQ message. If the host is the destination node of the request, the host sends the route request reply message (RREP) backward to the source node. Otherwise, the mobile host appends in RREQ message and re-forwards it to reachable next-hop by the dual-mode interface.

To reduce the traffic load of the wireless network, when an intermediate host receives the RREQ message, it checks whether the time of searching routing path is smaller than the on demand “Time to Live” and the current total number of intermediate hosts is smaller than on demand threshold.

To discover a routing path, assume that all the hosts in hybrid wireless network are a set S.

\[ S = \{N_1, N_2, N_3, \ldots, N_k\} \]  

where \( k \) is the number of nodes (MH or BS) in the hybrid wireless network. When the route discovery process finished, multiple paths may be discovered. Then, the routing paths discovered can be defined as:

\[ \text{RouteDiscovery}(N_{src}, N_{dest}) = \{R_1, R_2, R_3, \ldots, R_n\} \]  

where \( n \) is the number of paths found, \( N_{src} \) and \( N_{dest} \), the total number of intermediate nodes in \( R_i \), \( n \) : the number of paths found in route discovery phase.

2.2.3 Route Selection Phase
After the route discovery phase, there may be many routing paths found. To select an optimal routing path for communication becomes an important issue. To apply and compare with the existing dynamic source routing protocol [5] and location stability routing protocol [6] in the hybrid wireless network, these two routing protocol are modified as hybrid-dynamic source routing protocol (H-DSR) and hybrid-location stability routing protocol (H-LSR).

According to Eq. (13), the routing path \( R_i \) of H-LSR should satisfy the on demand location stability limitation such as \( L_{N_j}(t-1) - L_{N_i}(t) \leq \Delta T1 \leq L_{N_i}(t-1) \) the indicates the location of \( N_j \) in time t-1 and the \( L_{N_i}(t) \) is the location of \( N_i \) in time t. The \( L_i \) is the on demand given location stability range. Then, the routing metric function of the H-DSR and H-LSR can be defined as follows:

\[ \text{RM}(R_i) = |R_i|, 1 \leq i \leq n \]  

where \( n \) is the number of paths found in route discovery phase. Moreover, the routing selection function of H-DSR and H-LSR, which selects the shortest routing path, is defined as follows:

\[ \text{RSelect}(\text{RouteDiscovery}(N_{src}, N_{dest})) = \min \{\text{RM}(R_1), \text{RM}(R_2), \ldots, \text{RM}(R_n)\} \]  

In contrast, the proposed routing selection measurement (RSM) considers the transmission time, power consumption, and the total number of intermediate nodes used. The transmission time of the route is defined as:

\[ \text{Transmission Time}(R_i) = \frac{\text{Data Size}}{\frac{\min\{\text{Avail BW(N_1)}, \ldots, \text{Avail BW(N_{dest})}\}}{1}} \]
where \( \text{Avail}_\text{BW}(N_i) \) indicates available bandwidth of node \( N_i \). In addition to bandwidth, to transmit data packets to the next intermediate node consumes battery power. According to Eq. (5), we assume that the power cost of packets transmission is \( P_{\text{C}} \). To minimize the transmission time with less intermediate nodes, we design the routing metric function of our routing selection measurement as follows:

\[
\text{RM}_{\text{min}}(R_i) = \left( \text{REQ}_\text{bandwidth} - \min_{1 \leq i \leq n} \text{Avail}_\text{BW}(R_i) / \text{REQ}_\text{bandwidth} \right) + |R_i| + P_i
\]

which is subject to \( 1 \leq i \leq n \) and \( \min_{1 \leq i \leq n} \text{Avail}_\text{BW}(R_i) \cdot \min(\text{Avail}_\text{BW}(N_i), \text{Avail}_\text{BW}(N_k)), \ldots, \text{Avail}_\text{BW}(N_n)) \) where \( \text{REQ}_\text{bandwidth} \) indicates the request bandwidth of node \( N_{\text{src}} \). The proposed routing selection measurement is defined as:

\[
\text{RM}_{\text{min}}(\text{RouteDiscovery}(N_{\text{src}}, N_{\text{det}})) = \min\{\text{RM}_{\text{min}}(R_1), \text{RM}_{\text{min}}(R_2), \ldots, \text{RM}_{\text{min}}(R_n)\}
\]

Especially, if \( \text{RM}_{\text{min}}(R_1) \) and \( \text{RM}_{\text{min}}(R_2) \) are the same, the route with higher average value of available bandwidth is selected.

2.3 Handoff and Maintenance Process

The handoff and maintenance process is shown in Fig. 3. If there is a communication established, the state of this communication is checked. When the communication is not finished yet, the interruption state of this communication should be examined. If the communication is interrupted, the mobile device will execute the route discovery phase to find a new route to the destination device or base station. The maintenance process is that a device checks the communication state and runs the route discovery process to re-find a route for communication. If the communication is not interrupted, the base station has to execute the handoff phase. Since the base station has executed the type selection process, the suitable type of handoff has been chosen for the current communication.

3 Simulation

3.1 Type Selection Process

In the cellular system, suppose that the value of \( \beta \) is from 0.1 to 2. The handoff processing time \( t_h \) is smaller than 0.01 second. The radius of the base station’s communication coverage is 100. The current average velocity within the base station coverage, \( v_{\text{avg}} \), is set from (a) \( v_{\text{avg}} = 0.2 \), (b) \( v_{\text{avg}} = 10 \), (c) \( v_{\text{avg}} = 25 \), (d) \( v_{\text{avg}} = 50 \), to (e) \( v_{\text{avg}} = 100 \). In addition, the moving speed of a new joint arbitrary mobile device is set randomly from 0.1 to 50 for the comparisons of different mobility.

In Fig. 4, the proactive type decision is indicated as 1. Figs. 4-(a) to 4-(e) indicate the different average velocity. When the value of \( v_{\text{avg}} \) and the random value of the one node’s moving speed \( v_i \) increase, the probability of a mobile device classified as the reactive routing are from 98.44% in Fig. 4-(a) to 9.16% in Fig. 4-(e). Therefore, one can set the value of \( \beta \) on demand to reduce the final total costs.

In MANET, there are six parameters that affect the final decision based on Eq. (10). One can fix four out of six parameters to observe the behavior of these parameters. Fig. 5 shows the total cost obtained from (a) the proactive type protocol, (b) the reactive type protocol, and (c) the proposed type selection process are shown in Fig. 5. The proposed type selection process takes advantage of each routing protocol to reduce the total cost of routing path searching.

3.2 Routing Discovery Process, Handoff and
Maintenance Process
In order to form a hybrid wireless environment, we distribute base stations within a 3×3 matrix. The coverage of each base station is 1000×1000 square meters. The distributed position of mobile hosts is randomly generated and located. All mobile hosts are registered to base station.

The specifications of the dual-mode interface about bandwidth and transmission range are set initially to the ideal maximum value of related standard [7]. The classes of request bandwidth are given to mobile host randomly. Moreover, we vary the maximum moving speed of mobile hosts from 0, 3, 8, 12 m/s and divide them into 4 classes. The maximum hops of forwarding data is set to 10. More specifically, Table 1 summarizes the parameters used in the simulation environment.

Table 1. Simulation parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of base stations</td>
<td>9</td>
</tr>
<tr>
<td>Coverage of base stations</td>
<td>1000×1000 square meters</td>
</tr>
<tr>
<td>Dual-mode interface specification</td>
<td>CDMA2000 1x/EVDO</td>
</tr>
<tr>
<td></td>
<td>IEEE 802.11b</td>
</tr>
<tr>
<td>Max hops of each route</td>
<td>10</td>
</tr>
<tr>
<td>AdHoc ServiceRate</td>
<td>SR/Service Rate/2</td>
</tr>
<tr>
<td>Cellular ServiceRate</td>
<td>SR/Service Rate/2</td>
</tr>
<tr>
<td>Pausing time</td>
<td>1 s</td>
</tr>
<tr>
<td>Request bandwidth</td>
<td></td>
</tr>
<tr>
<td>Class 0</td>
<td>0 kbps (No Request)</td>
</tr>
<tr>
<td>Class 1</td>
<td>50–100 kbps</td>
</tr>
<tr>
<td>Class 2</td>
<td>100–200 kbps</td>
</tr>
<tr>
<td>Class 3</td>
<td>200–400 kbps</td>
</tr>
<tr>
<td>Class 4</td>
<td>400–600 kbps</td>
</tr>
<tr>
<td>Mobility model</td>
<td>Random Way-Point model</td>
</tr>
<tr>
<td>Mobile host mobility</td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>0 m/s (Fixed)</td>
</tr>
<tr>
<td>Class 2</td>
<td>1–3 m/s (slow)</td>
</tr>
<tr>
<td>Class 3</td>
<td>4–8 m/s (medium)</td>
</tr>
<tr>
<td>Class 4</td>
<td>9–12 m/s (fast)</td>
</tr>
</tbody>
</table>

We compare the proposed routing protocol with H-DSR and H-LSR which are heterogeneous version of dynamic source routing protocol and location stability routing protocol. In Fig. 6, the proposed routing selection measurement (RSM) reduces the request block rate about 12–17% compared with H-DSR and H-LSR.

![Fig. 6. Comparisons of the request block rate of RSM, H-LSR and H-DSR.](image)

Comparison of the transmission time among H-DSR, H-LSR and the proposed routing selection measurement is shown in Fig. 7. The transmission time of the proposed routing selection measurement is about 5–22% lower than that of H-DSR and H-LSR. In simulation, the size of deliver data is set to 1Mb.

![Fig. 7. Transmission time of H-DSR and H-LSR vs.](image)

transmission time of the proposed RSM.

4 CONCLUSION
The adaptive management for heterogeneous wireless networks is proposed. For handoff, the simulation results verify the performance of the type selection process and handoff and maintenance process.

The type selection process can reduce the total cost from 9.16% to 98.44%. The proposed routing selection measurement (RSM) in route selection phase can reduce the block rate of communication about 12–17% compared with the competing algorithms. It can reduce the transmission time about 5–22% compared with the heterogeneous versions of dynamic source routing protocol and the location stability routing protocol.

References: