Relaying Capability-Based Routing for Improving Service Availability in Multi-hop Cellular Networks

Ming-Hua Lin

Department of Information Management, Shih Chien University
70 Ta-Chih Street, Taipei 104, Taiwan

Summary
Multi-hop cellular networking models that integrate the characteristics of both cellular and mobile ad hoc networks have received increasing attention. Finding an available relaying path is a critical prerequisite for the success of the multi-hop cellular networks. Most works use signal strength, path length and power consumption as routing criteria to select a relaying path for a mobile node reaching the central base station. Such methods cannot react effectively to the individual impact of each intermediate mobile node contributing to successful hop-by-hop connections. Moreover, forwarding data for others utilizes the resources of the mobile nodes such as battery energy, link bandwidth, buffer space and processing time, the mobile nodes may accept only a limited number of relaying requests. This paper presents a novel routing scheme based on the relaying capability of each mobile node to decrease call blocking probability and handoff call blocking probability, therefore enhancing service availability in the networks. Simulation results indicate that the proposed routing scheme results in higher service availability than the shortest-path routing scheme under a certain constraint on maximum relaying capacity of each mobile node.

Key words: *relaying capability, routing scheme, network performance, multi-hop cellular networks*

Introduction

Multi-hop cellular networking has been an active research area in recent years. In conventional cellular networks, mobile stations communicate directly with their assigned base station; in wireless multi-hop networks, mobile stations are located randomly and use peer-to-peer communications to relay their messages. Multi-hop cellular networks that integrate the characteristics of both cellular and mobile ad hoc networks to leverage the advantages of each other, such as energy consumption conservation, number of fixed antennas decrease, cell capacity enhancement and coverage extension [1-4,14,15]. Figure 1 indicates the scenario of general multi-hop cellular networks, the service area of the cellular networks can be extended by hop-by-hop connections at the boundaries of the cell or the dead spot locations can be supported by relaying connections through the wireless devices with good channel quality.

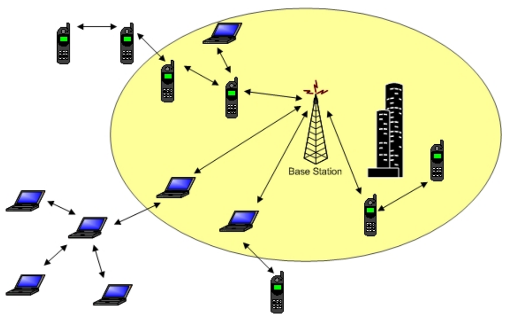

Fig. 1 Scenario of general multi-hop cellular networks.

In multi-hop cellular networks, packets must be relayed hop by hop from a given mobile node to a base station and vice-versa. Therefore, finding an available relaying path is a critical prerequisite for the success of the multi-hop cellular networks. Most of the multi-hop cellular networking models do not have a pre-constructed routing topology for forwarding packets. The mobile nodes find relaying paths when they desire to transmit data. Although the shortest path is the most simple and common metric used in the routing protocol, it may route almost packets over a few (shortest-distance) paths and result in network congestion and resource unavailable in hot spot [5].

Since forwarding data for others utilizes the resources of the mobile nodes such as battery energy, link bandwidth, buffer space and processing time, the mobile nodes may accept only a limited number of relaying requests. In this paper, we present a relaying capability-based routing scheme to select a relaying path between a mobile node and the central base station according to the individual impact of each intermediate node on supporting hop-by-hop connections. The importance of each mobile node is evaluated by a metric which represents the relaying capability of the node. The proposed routing scheme can retain more valuable resource for later relaying requests,

Manuscript received March 5, 2006.
Manuscript revised March 25, 2006.

thereby supporting more connections successfully. Simulation results indicate that the relaying capability-based routing scheme causes high service availability than the shortest-path routing scheme under a certain constraint on maximum relaying capacity of each mobile node.

The rest of this paper is organized as follows. In section 2, we review the routing schemes in existing multi-hop cellular networking models. Section 3 describes the detail of the proposed relaying capability-based routing scheme. Section 4 presents the simulation results and discussions. Finally, concluding remarks are recommended in section 5.

2. Literature Review

The routing schemes in multi-hop cellular networks are similar to that in pure ad hoc networks. Some research has reviewed and investigated existing multi-hop routing protocols [7-9]. The mobile nodes discover relaying paths when they desire the path to transmit data depending on different criteria, such as signal strength, path length and power consumption [6].

Opportunity Driven Multiple Access (ODMA) is an ad hoc multi-hop protocol that the transmissions from mobile hosts to the base station are broken into multiple wireless hops, thereby reducing transmission power [1,10]. Previous work on ODMA uses path loss between terminals as the metric to determine the routing path. From the list of relaying routes available, the one with minimum aggregate transmit power along the route is selected. Rouse et al. presented a routing scheme considering receiver interference on ODMA [1].

Aggélou et al. described an Ad Hoc GSM (A-GSM) system that presents a network layer platform to accommodate relaying capability in GSM cellular networks [11]. In A-GSM system, handover is initiated by a mobile node when a high possibility exists that the call will be lost or the quality of the ongoing connection seriously degraded. The mobile nodes measure the signal strength of the surrounding A-GSM nodes and the connected base stations. When the criteria for changing the serving base station or the serving relay is satisfied, such as the existing serving base station failure, the A-GSM handover will be triggered. If multiple neighboring nodes are available for a mobile node to build a relaying path to the base station, the mobile node selects a relaying link with strongest signal to initiate handover.

Qiao et al. presented a network model called iCAR that integrates the cellular infrastructure and ad-hoc relaying technologies [2]. In iCAR system, a number of specific stations called ARS's are deployed at strategic locations to relay data from the congested cell to the neighboring non-congested cells. Each ARS collects neighbor information and maintains a routing table containing one entry for every reachable Base Transmission Stations (BTS). The ARS reports this information to a Mobile Switching Center (MSC) that controls a number of BTS's. The topology map can then be calculated by MSC's and only the updated part relevant to the ARS's is broadcast by the corresponding BTS to all ARS's in the cell. Whenever a mobile node needs a relaying path to one or more BTS's which have free channel available, the mobile node chooses the best ARS with the shortest path or the lowest power consumption as the proxy ARS to relay data to the target BTS.

Wu et al. proposed a scheme called Mobile-Assisted Data Forwarding (MADF) to add an ad-hoc overlay to the fixed cellular infrastructure and special channels are assigned to connect users in a hot cell to its neighboring cold cells [12]. In MADF approach, the user in a hot cell selects a forwarding agent according to the quality of the signal and the traffic load.

3 Relaying Capability-based Routing Scheme

The common approach in most existing routing protocols is to consider the shortest-path routing. For simplicity, these protocols measure the distance of the path by the number of hops in the path. However, routing packets based on minimum hop count may take a considerable time to reach the destination because almost packets may be routed over a few (shortest-distance) paths in the networks [5]. Additionally, forwarding data for others utilizes the resources of the mobile nodes such as battery energy, link bandwidth, buffer space and processing time. Consequently, each mobile node may accept only a limited number of relaying requests. For example, in A-GSM system [11], a protocol parameter "*relaying capacity*" is used to tell neighboring nodes the number of calls a mobile node can simultaneously relay.

In this section, we present a routing scheme to select a relaying path based on the individual importance of each intermediate node contributing to hop-by-hop connections. The proposed scheme aims to retain the nodes with more valuable relaying capability for later relaying requests, thereby setting up more connections successfully in the networks. Herein we focus only on a single base-station cell as indicated in Fig. 2. The base station can enhance the service coverage by adopting relaying connections supported by the mobile nodes.

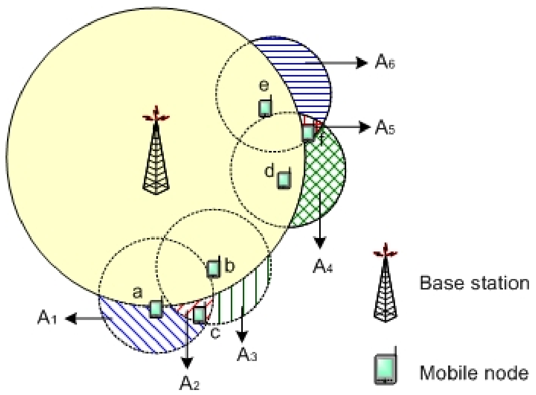

Fig. 2 An example of multi-hop cellular networks with a single base station.

In order to evaluate the degree of a mobile node contributing to relaying connections in the multi-hop cellular networks, we introduce a new metric called **relaying capability** (RC) as follows:

$$RC_v = \frac{1}{C_v} * (\sum_{i \in A_v} \frac{1}{RI_i}). \qquad (1)$$

C_v is the number of relaying requests that node v can accept simultaneously, A_v is the area inside the coverage of node v where the mobile node requires hop-by-hop connections to reach the base station, RI_i is the relay index (RI) of position i that is defined to be the number of mobile nodes capable of relaying traffic for a mobile node staying in position i. As the example indicated in Fig. 2, $RI_{i \in A_1}$ is 1 because only node a can relay data for the mobile nodes reside in area A_1; $RI_{i \in A_2}$ is 2 because both node a and node b can relay data for the mobile nodes reside in area A_2. Assume both node a and node b can support two relaying connections simultaneously, the degrees of node a and node b contributing to the relaying connections of networks are evaluated by their RC values as follows:

$$RC_a = \frac{1}{2}\sum_{i \in A_a} \frac{1}{RI_i} = \frac{1}{2}\sum_{i \in (A_1 \cup A_2)} \frac{1}{RI_i} = \frac{1}{2}(A_1 * \frac{1}{1} + A_2 * \frac{1}{2}) \qquad (2)$$

$$RC_b = \frac{1}{2}\sum_{i \in A_b} \frac{1}{RI_i} = \frac{1}{2}\sum_{i \in (A_2 \cup A_3)} \frac{1}{RI_i} = \frac{1}{2}(A_2 * \frac{1}{2} + A_3 * \frac{1}{1}) \qquad (3)$$

From above equations, RC_a is greater than RC_b because the coverage of area A_1 is larger than that of area A_3.

In Fig. 2, if node d can support two relaying connections but node e can support four relaying connections, and the coverage of area A_4 is equal to that of area A_6, then the relaying capability of node d and node e can be computed as follows:

$$RC_d = \frac{1}{2}\sum_{i \in A_d} \frac{1}{RI_i} = \frac{1}{2}\sum_{i \in (A_4 \cup A_5)} \frac{1}{RI_i} = \frac{1}{2}(A_4 * \frac{1}{1} + A_5 * \frac{1}{2}) \qquad (4)$$

$$RC_e = \frac{1}{4}\sum_{i \in A_e} \frac{1}{RI_i} = \frac{1}{4}\sum_{i \in (A_5 \cup A_6)} \frac{1}{RI_i} = \frac{1}{4}(A_5 * \frac{1}{2} + A_6 * \frac{1}{1}) \qquad (5)$$

From above equations, RC_d is greater than RC_e because the number of relaying requests node d can support simultaneously is fewer than that of node e.

There are three conditions that node v has a higher RC value:

- The node v has a larger A_v, which means it can support larger coverage where mobile nodes necessitate hop-by-hop connections to reach the base station.
- The position inside A_v has a lower RI value, which means the mobile nodes inside A_v can be supported by fewer nodes. That is, the node v can provide relaying services to the nodes that others cannot support.
- The node v has a lower C_v, which implies its relaying resource will be exhausted easily.

Consequently, a node with a higher RC value represents that its resource is more valuable. Let IM_r be the set of intermediate nodes (the nodes in the route except the source and the destination) in route r, TRC_r be the sum of the RC values of all intermediate nodes on the route r, that is,

$$TRC_r = \sum_{v \in IM_r} RC_v \qquad (6)$$

Let R_i be the set of routes from node i to the base station, we select the route with minimum TRC value as the relaying path for connecting node i to the base station. That is, the routing criteria is

$$\min_{r \in R_i}\{TRC_r\} \qquad (7)$$

As the example illustrated in Fig. 2, node c has two choices to route data to the base station: $c \rightarrow a \rightarrow BaseStation$, $c \rightarrow b \rightarrow BaseStation$. The TRC values of these two routes are as follows:

$$TRC_{c \rightarrow a \rightarrow BaseStation} = RC_a \tag{8}$$

$$TRC_{c \rightarrow b \rightarrow BaseStation} = RC_b \tag{9}$$

In our routing scheme, node c selects the relaying path $c \rightarrow b \rightarrow BaseStation$ because RC_b is less than RC_a . Similarly, node f selects the relaying path $f \rightarrow e \rightarrow BaseStation$ because RC_e is less than RC_d . The proposed routing scheme selects a relaying path with minimum sum of the RC values of all intermediate nodes in the path. As the RC value defined in equation (1) and above discussions, a node with a higher RC value has more relaying capacity and can support larger coverage or provide relaying services to the nodes that few nodes can also support. Consequently, selecting a relaying path with minimum TRC value first makes more valuable resource retain for later relaying connections or for the mobile nodes that may not be served by others.

In [13], Ahmed et al. proposed a method to determine the trajectory of the mobile gateway to serve the ad hoc group to which it belongs. A mobile gateway called Cross-Layer Communication Agent (CCA) provides connection between a group of ad hoc mobile nodes and a range extension network. Each cluster with a CCA and a group of mobile nodes in [13] is an example of the multi-hop cellular networking models mentioned in this paper. Ahmed et al. defined theCCA trajectory based on the location, traffic load, etc. Since the position of each node is required for computing the optimal location of the CCA, each node is equipped with a GPS device that enables the node to determine its position. For measuring the RC value of a node proposed in this paper, each mobile node is also equipped with a GPS device to obtain its position. The mobile node can report which position it can support based on its location and signal strength. The RI value of each position depends on the number of mobile nodes capable of providing relaying services for it. Suppose all nodes participating in routing are able to reach the base station by hop-to-hop connections. After each mobile node transmits its maximum relaying capacity and the positions it can serve to the central base station, the central base station can compute an optimal route for each request from the received information.

4 Simulation Results and Discussions

The simulation environment is a rectangular region of size 600 units by 600 units with a single base station located in the central point. The radius of the base station is 150 units and the radius of each mobile node is 100 units. Each simulation runs for 100 seconds. The maximum relaying capacity for each mobile node is set randomly between 2 and 6. The mobile nodes move according to a random waypoint mobility model [5]. Each mobile node starts its journey from a random location to a random destination with a randomly chosen speed (uniformly distributed between 0-12 units/s). Once the destination is reached, another random destination is targeted after a 10-second pause time. The arrival of new data transmission requests initiating in each mobile node forms a Poisson process with rate λ=0.2 calls/second and the data transmission times are exponentially distributed with mean 10 seconds.

We compare the proposed relaying capacity-based routing scheme with the shortest path routing scheme in service availability. In multi-hop cellular networks, the services provided by the base station are available when the mobile nodes can connect to the base station successfully. Herein we define the service availability in the multi-hop cellular networks as follows:

$$P_{sa} = 1 - (\alpha P_{nb} + \beta P_{hb}) , \tag{10}$$

where α and β are constants that denote the penalty associated with new call blocking probability (P_{nb}) and handoff call blocking probability (P_{hb}), respectively, ($\alpha + \beta = 1$), with $\beta > \alpha$ to reflect that users are more sensitive to call dropping than new call blocking [14]. In our simulation, parameter α and β in Eq. (10) are set to be 0.4 and 0.6 respectively, which means that we treat handoff call dropping more important than new call blocking. The shortest path is determined by the relaying path with minimum hops. If a mobile node desires to transmit data to the central base station but no relaying path is available or any node in the relaying path has accepted maximum relaying requests, then the new call blocking probability is 1. After a mobile node finds an available path and connects to the base station successfully, handoff is initiated when current relaying path can not support ongoing connection due to location changement. If a relaying path is not available when a mobile node initiates handoff, then the handoff call blocking probability is 1.

In Fig. 3, we observe that the relaying capability-based routing provides higher service availability than the shortest-path routing under various number of mobile nodes. Since the mobile nodes do not accept more relaying requests than its limited capacity, shortest path routing that forwards packets over a few paths causes network congestion and resource unavailable in hot paths and results in higher new call blocking probability and handoff call probability under a certain constraint on maximum relaying capacity of each mobile node.

Moreover, we can find service availability is low when number of mobile nodes is small. This implies that finding an available path when fewer mobile nodes exist in the networks is more difficult. In Fig. 4, we observe that the average path length in the relaying capacity-based routing scheme is longer than that in the shortest-path routing scheme since the shortest-path routing scheme has minimum hops to reach the base station. However, the difference is not obvious.

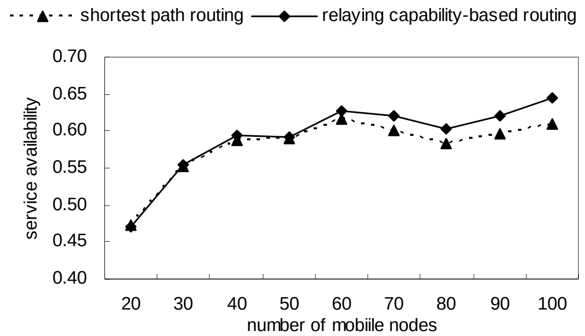

Fig. 3 Comparison of service availability by relaying capability-based routing and shortest-path routing under different number of mobile nodes

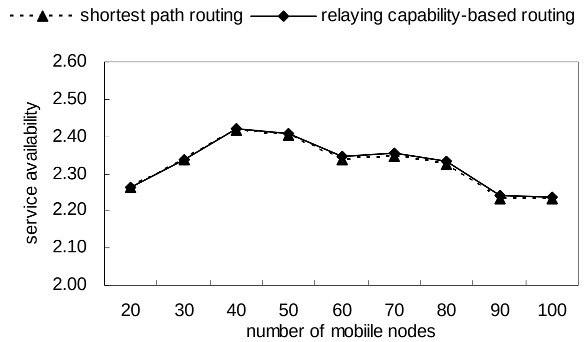

Fig. 4 Comparison of average path length by relaying capability-based routing and shortest-path routing under different number of mobile nodes

5. Conclusions

In this paper, we propose a relaying capability-based routing scheme to select a realying path between a mobile node and the central base station based on the individual importance of each intermediate node contributing to hop-by-hop connections. The proposed routing scheme can retain more valuable resource for later relaying requests, thereby supporting more relaying connections successfully. Simulation results indicate that the proposed relaying capability-based routing scheme results in higher service availability than the shortest-path routing scheme under a certain constraint on maximum relaying capacity of each mobile node.

Acknowledgments

This research was supported by the Shih Chien University, Taiwan, under the contract USC 94-05-38807-11.

References

[1] Rouse, T., Band, I., McLaughlin, S.: Capacity and Power Investigation of Opportunity Driven Multiple Access (ODMA) Networks in TDD-CDMA Based Systems, Proc. of IEEE ICC, pp.3202-3206, Apr. 2002.

[2] Qiao, C., Wu, H.: iCAR: an Intelligent Cellular and Ad-hoc Relay System, Proc. of IEEE IC3N, pp.154-161, Oct. 2000.

[3] Jakobsson, M., Hubaux, J.P., Buttyán, L.: A micropayment scheme encouraging collaboration in multi-hop cellular networks, Proc. of Financial Crypto 2003.

[4] Ben Salem, N., Buttyán, L., Hubaux, J.P., Jakobsson, M.: A Charging and Rewarding Scheme for Packet Forwarding in Multi-Hop Cellular Networks, Proc. of ACM MOBIHOC, pp.13-24, Sep. 2003.

[5] Sheu, S.T., Chen, J.H.: Novel Delay-Oriented Shortest Path Routing Protocol for Mobile Ad Hoc Networks, Proc. of IEEE ICC, pp.1930-1934, Jun. 2001.

[6] Singh, S., Woo, M., Raghavendra, C.S.: Power-Aware Routing in Mobile Ad Hoc Networks, Proc. of ACM/IEEE International Conference on Mobile Computing and Networking, pp.181-190, Oct. 1998.

[7] Royer, E.M., Toh, C.K.: A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks, IEEE Personal Communications, pp.46-55, Apr. 1999.

[8] Safwat, A., Hassanein, H.: Infrastructure-based Routing in Wireless Mobile Ad Hoc Networks, Journal of Computer Communications 25, pp.210-224, 2002.

[9] Broch, J., Maltz, D.A., Johnson, D.B., Hu, Y.C., Jetcheva, J.: A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols, Proc. of ACM MOBICOM, pp.85-97, Oct. 1998.

[10] 3G TR 25.924 V 1.0.0. 3GPP TSG-RAN; Opportunity Driven Multiple Access, Dec. 1999.

[11] Aggélou, G.N., Tafazolli, R.: On the Relaying Capacity of Next-Generation GSM Cellular Networks, IEEE Personal Communications, pp.40-47, Feb. 2001.

[12] Wu, X., Chan, S.H., Mukherjee, B.: MADF: A novel approach to add an ad-hoc overlay on a fixed cellular infrastructure, Proc. of IEEE WCNC, pp.549-554, Sep. 2000.

[13] Ahmed, M., Krishnamurthy, S., Katz, R., Dao S.: Trajectory control of mobile gateways for range extension in ad hoc networks, Computer Networks 39(6), pp.809-825, 2002.

[14] Hou, J., Yang, J., Papavassiliou, S.: Integration of pricing with call admission control to meet QoS requirements in cellular networks, IEEE Transactions on Parallel and Distributed Systems 13(9) pp.898-910, Sep. 2002.

[15] Lindström, M., Lungaro, P.: Resource delegation and rewards to stimulate forwarding in multihop cellular networks, Proc. of IEEE VTC, pp.2152-2156, May 2005.
[16] Wei, H.Y., Gitlin, R. D.: Incentive Scheduling for Cooperative Relay in WWAN/WLAN Two-Hop-Relay Network, Proc. of *IEEE Wireless Communications & Networking Conference (WCNC 05')*, pp.1696-1701, Mar. 2005