Enhancement of Cellular IP Routing by Redirection at Crossover Base Stations

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Abstract- The original routing scheme in Cellular IP (CIP) requires all data packets regardless of their destinations to be routed to the gateway first before being routed to the destination, which is inefficient for internal traffic within the same network and also results in higher traffic load in nearby links of the gateway. In this paper, an enhanced routing mechanism called Redirected CIP (R-CIP) is proposed. R-CIP takes advantage of the redirection at the crossover base stations to shorten the transmission path. Because of the simplicity of R-CIP, only a little modification of CIP is required to support R-CIP. An extension of R-CIP for multicast routing (denoted by MR-CIP) is also proposed in the paper. Simulation results have demonstrated the better performance of R-CIP and MR-CIP over standard CIP-based schemes in terms of routing efficiency as well as the reduction of link load.

Keywords: Cellular IP, Mobility Management, Multicast

I. INTRODUCTION

With the advent of personal communications technologies and increasing demand of IP services for mobile users, mobility management [1-4] for IP-based data services has obtained intensive researches in recent years. Mobility management is an essential component in enabling mobility of hosts while maintaining the packet routing efficiency between the hosts. *Mobile IP* [5, 6] was proposed to support global Internet mobility through the introduction of location directories and address translation agents. It is widely accepted that Mobile IP is inadequate for high mobility users in which frequent handoff is the common case, and instead, *Cellular IP* (*CIP*) [7-11] was proposed.

CIP provides local mobility and handoff support for frequently moving hosts, which means that mobile hosts can migrate inside a CIP Network with little disturbance to active data flows. It was pointed out in our previous work [11] that the handoff and routing mechanisms in CIP require all the data packets to be routed to the gateway before being routed to the destination. It results in a bad consequence that for *internal traffic* of which the packets are transmitted by a mobile host in the CIP network and destined to another mobile host in the same CIP network, the traffic is still routed to the gateway first, even the destination of the traffic is connecting to the same base station as the sender or a neighboring base station. It implies that the gateway is inevitably becoming a hot spot of traffic and therefore results in the phenomenon of load unbalance among wired links in the CIP network.

In this paper, an enhancement of CIP routing and handoff scheme is proposed to provide better routing efficiency for internal traffic in a network with tree topology. The idea is based on the redirection at the crossover base station of the sender and the receiver. The enhanced version of CIP is called *Redirected CIP* (*R-CIP*). Moreover, we also extend R-CIP to support multicast transmission within the same network, which is denoted by *MR-CIP* (*Multicast extension of R-CIP*). Simulation study has demonstrated that R-CIP and MR-CIP achieve better performance over standard CIP-based schemes in terms of routing efficiency as well as the reduction of link load.

The rest of the paper is structured as follows. The basic idea and mechanisms of R-CIP are explained in section II. Multicast extension of R-CIP (MR-CIP) is presented in section III. Simulation environment and results for performance evaluation are presented in section IV. Finally, section V concludes this paper.

II. REDIRECTED CIP (R-CIP)

A. Basic idea

As shown in Figure 1-(a), standard CIP routing requires data packets to be routed to the gateway before being routed to the receiver, since data packets in CIP are used to create or refresh the downlink path from the gateway to the packet source mobile host. For the sake of shortening routing path, data packets should not go beyond the crossover base station of the sender and the receiver. This is the basic idea of R-CIP. Therefore, as illustrated in Figure 1-(b), the crossover base station of the sender and the receiver in R-CIP is responsible for redirecting data packets to the receiver, which means the gateway is no longer the only station that redirects data packets.

More specifically, in R-CIP, when a base station (e.g. BS2 in Figure 1) has received a data packet from a descendent base station, the base station (BS2) checks if it has the cache data for the downlink of the packet destination. If so, the base station identifies itself the crossover base station of the packet

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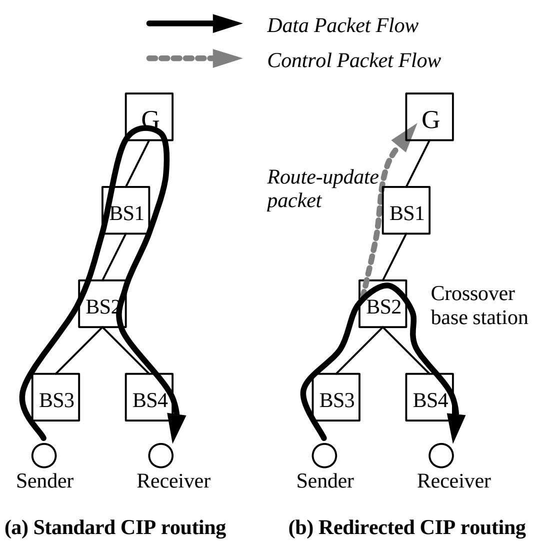


Figure 1. Standard CIP vs. Redirected CIP

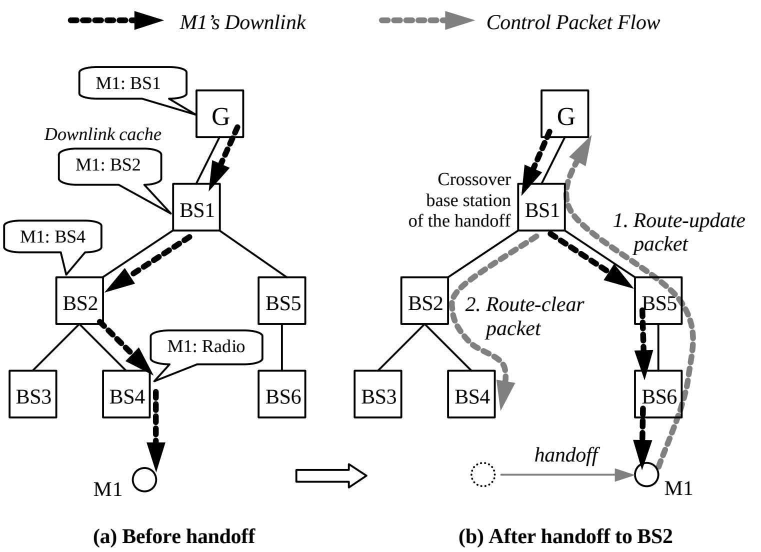


Figure 2. R-CIP Handoff Scheme

transmission and is responsible for redirecting the data packet to the receiver.

Moreover, the crossover base station also needs to issue a *route-update* packet (a signaling packet defined in standard CIP, whose size is usually much smaller than that of data packets) to refresh the downlink path on behalf of the packet sender.

B. R-CIP handoff scheme

The handoff of an active mobile host results in the change of the crossover base station for any possible data transmission. Therefore, in order not to let obsolete cache data (i.e. wrong downlinks) lead to wrong redirection, the handoff scheme in standard CIP must be modified. In standard CIP, obsolete downlink cache is cleared due to timer expiration, which is still adopted in R-CIP. However, in order to reduce packet loss ratio due to wrong redirection, the crossover base station of the handoff (i.e. the crossover of the old and the new base stations) issues a new signaling packet, *route-clear* packet, to explicitly clear obsolete cache along the old downlink path.

As illustrated in Figure 2, when a mobile host M1 moves from BS4 to BS6, it has to transmit a *route-update* packet along its uplink path to the gateway as in standard CIP. When base station BS1 receives the *route-update* packet and finds out that the cache data of M1 needs to be updated (not created), base station BS1 identifies itself as the crossover base station of the handoff and issues a *route-clear* packet along the previous downlink path of M1 to clear obsolete caches.

III. MULTICAST EXTENSION OF R-CIP (MR-CIP)

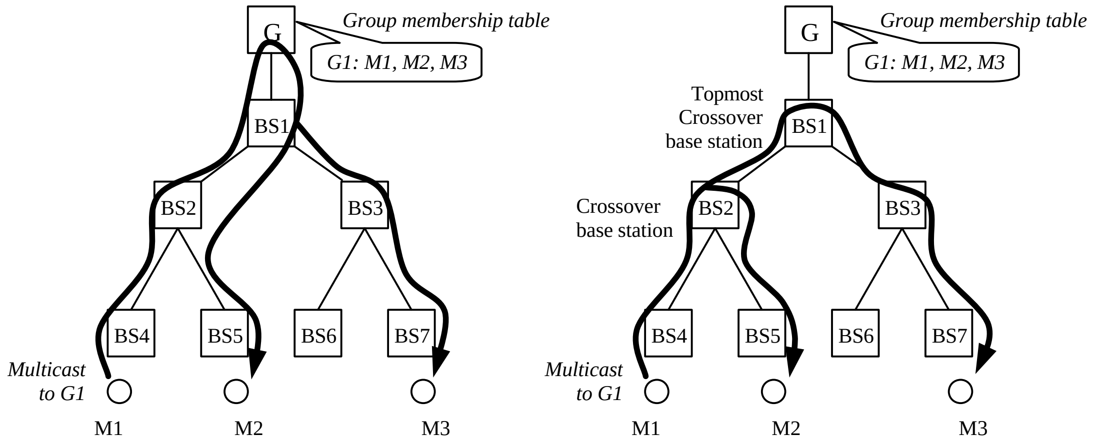
A. Group membership and Group downlink

As mentioned in our previous work [11], the most straightforward way to extend standard CIP for multicast support is to equip the gateway with the ability of group management and be responsible for multicast transmission. The protocol is called *Gateway-based multicast protocol* (*GBMP*). Since the gateway maintains the member list for each multicast group, the gateway forwards the multicast packet to the group members. There are two ways of forwarding a multicast packet to group members in GBMP, *unicast-based* and *multicast-based*. Unicast-based GBMP makes use of multiple unicastings to support multicasting. Multicast-based GBMP requires the member information of the destination group to be carried in the data packet (in *IP Route Option* field) so that each en route base station can decide which downlink the base station should forward the packet to. Multicast-based GBMP is called *GBMP with Route Option* (*GBMP-RO*). An example of multicast routing in GBMP-RO is shown in Figure 3-(a).

In MR-CIP, the gateway is also responsible for group membership management. However, as illustrated in Figure 3-(b), multicast routing in MR-CIP takes advantage of redirection at crossover base stations to achieve better routing performance. Redirection at crossover base stations for multicasting among group members requires related base stations in the multicast tree to maintain proper membership information for the group. Therefore, a new cache called *group downlink* in MR-CIP is defined. Group downlink cache records members' ID of a group that a downlink can lead to and helps in redirecting multicast packets to proper downlinks. An instance of the group downlink includes the following fields: (1) *Group ID*, (2) *Next Base Station*, (3) *ID of the group members* this downlink can lead to, (4) *Yes/No Flag* indicating whether or not the base station is the topmost base station for the group. Manipulation of the group downlink is presented in the next subsection.

B. Constructing MR-CIP tree

When a mobile host wants to join a group, it sends out an *IGMP-Join* message to its base station. The *IGMP-Join*



(a) GBMP-RO Routing **(b) MR-CIP Routing**

Figure 3. GBMP-RO vs. MR-CIP

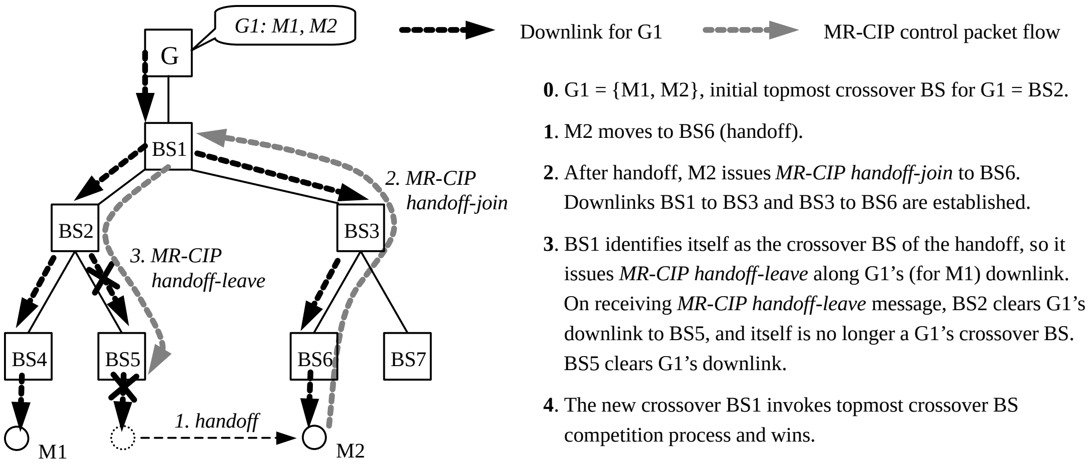


Figure 4. MR-CIP handoff scheme

message is then forwarded along the uplink path to the gateway. Each en route base station that relays the *IGMP-Join* message establishes group downlink cache for the newly member.

Note that there is a key point when constructing a MR-CIP tree: the determination of the *topmost crossover base station* in the tree. In GBMP, the gateway is always the topmost crossover station. On the other hand, in MR-CIP, each base station could probably be the topmost crossover base station for a group and it depends on the location of each group member. Moreover, in MR-CIP routing, a multicast packet should not go beyond the topmost crossover base station as shown in Figure 3-(b) so that multicast transmission cost can be reduced.

To become a topmost crossover base station for a group, a base station must be (1) a crossover base station, which means the base station must have more than one group downlink, and (2) the topmost one among all crossover base stations of the group. Therefore, to determine the correct topmost crossover base station, MR-CIP invokes a competition process (called *topmost competition process* in the paper) when (1) a new crossover base station forms, or (2) the previous topmost crossover base station is no longer a crossover base station for the group. During *topmost competition process*, each crossover base station claims that it is the topmost and notifies its upper and lower base stations of the claim. If the base station does not receive any objection message within a predefined time, it becomes the topmost crossover base station of the group.

C. MR-CIP Handoff scheme

MR-CIP tree of a group needs to be updated when a group member moves to a new base station. Thus, the handoff scheme in MR-CIP has to deal with the update of the group downlink when the handoff of a group member occurs. Two new signal messages for manipulating the group downlink cache during the handoff of group members are defined in MR-CIP: *MR-CIP handoff-join and MR-CIP handoff-leave.* After a member handoff to a new base station, it sends out a *MR-CIP handoff-join* message. The message is forwarded

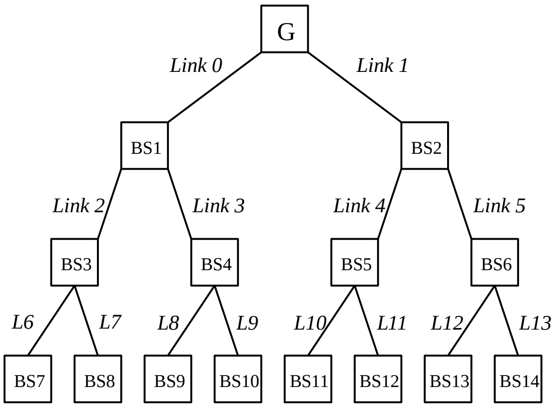


Figure 5. Network topology in the simulation

along the uplink path until it arrives at the crossover base station of the handoff. The crossover base station then sends out a *MR-CIP handoff-leave* message along the downlink path to clear the obsolete group downlink caches.

For example, as illustrated in Figure 4, group member M2 moves from base station B5 to B6. After the handoff, M2 sends out a *MR-CIP handoff-join* message, and new group downlinks are established. BS1 identifies itself as the crossover base station of the handoff and sends out a *MR-CIP handoff-leave* message to clear obsolete group downlinks. Moreover, BS1 invokes *topmost competition process* and wins. So BS1 becomes the topmost crossover base station of the group after the handoff.

IV. Performance Evaluation

A. Simulation environment and performance criteria

Simulation study has been conducted to evaluate the performance of R-CIP as well as MR-CIP. The topology of the network in the simulation is shown in Figure 5, in which the index of each wired link is assigned. There are 100 mobile hosts in the network moving among leaf base stations. In order to model the mobility of the hosts, time is slotted and a parameter called *MoveProb* (*Movement Probability*) is used in the simulation. *MoveProb* represents the probability that a mobile host leaves its current base station and moves to one of the neighboring base stations in the next time slot. Two performance criteria are defined for comparing the performance of R-CIP and MR-CIP with other schemes:

(1) A*verage transmission cost*

(2) *Relative load of each wired link*

The transmission cost is defined as the total number of data packets generated in the CIP network to transmit a packet to all group members. Relative load of each wired link is calculated as follows. The number of data packets transmitted in each wired link is recorded during the simulation. At the end of the simulation, the load of a wired link is computed as the number of packets transmitted in the link divided by the maximum number of packets among all wired links. That is, the load of the link with the maximum number of packets transmitted is set to 1, and the load of other links is calculated by normalizing the number of packets to the maximum number of packets.

Note that R-CIP is treated as a special case of MR-CIP with group size 2 and standard CIP (S-CIP) is treated as a special case of GBMP-RO with group size 2. Therefore, we only show the simulation results of MR-CIP and GBMP-RO in the following.

B. Simulation results

Average transmission costs for MR-CIP and GBMP-RO under different group sizes are displayed in Figure 6. It shows that MR-CIP outperforms GBMP-RO in terms of average transmission cost. Moreover, Figure 6 shows that MR-CIP can save up to 34% of the transmission cost over GBMP-RO for group size = 2 (i.e. unicast case). For multicast case, at least 20% of the transmission cost can be saved by MR-CIP.

Figures 7~9 display the relative load of each wired link in the network for MR-CIP and GBMP-RO with group sizes 2, 10, and 30 respectively. These figures demonstrate the better effect of load balancing as well as the efficiency of group communications by MR-CIP.

Please note that since the simulation results for different *MoveProb* values are quite close, we only display the case of *MoveProb* = 0.5 in the paper.

V. Conclusion

In this paper, we propose a simple but efficient routing scheme to improve standard CIP routing. The proposed scheme is called *Redirected CIP* (*R-CIP*). In standard CIP, data packets must be routed to the gateway before being routed to the receiver. The notion of redirection is adopted in R-CIP, in which the crossover base station of the sender and the receiver is responsible to redirecting data packets to the receiver. In this way, packet transmission cost can be reduced. *Multicast extension of R-CIP* (*MR-CIP*) and associated handoff scheme are also proposed in the paper. Simulation results have demonstrated the better performance of proposed redirection-based schemes in terms of transmission cost and link load balancing.

Lastly, R-CIP requires a little change in base station processing for redirection and a new signal packet (*route-clear*) is defined in R-CIP for explicitly clearing the obsolete downlink cache. In order to support MR-CIP, a new cache namely *group downlink cache* is defined and each base station has to be equipped with the ability for handing the group downlink cache as well as the *topmost competition process*. Moreover, two new signal messages for handling the group downlink cache during the handoff of a group member are defined.

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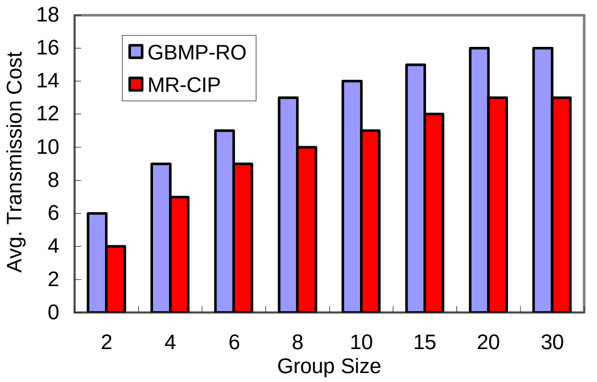

Figure 6. Average Transmission Cost (*MoveProb*=0.5)

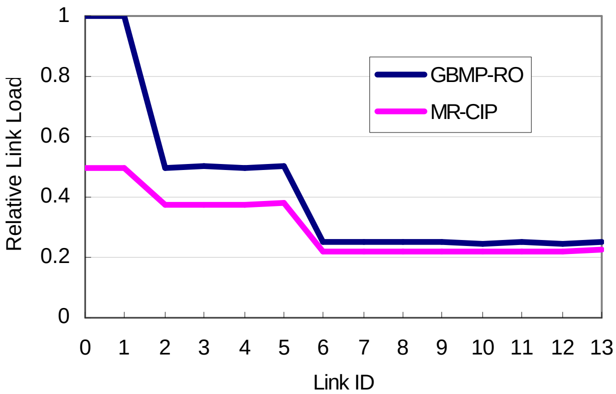

Figure 7. Related link load (Group size = 2)

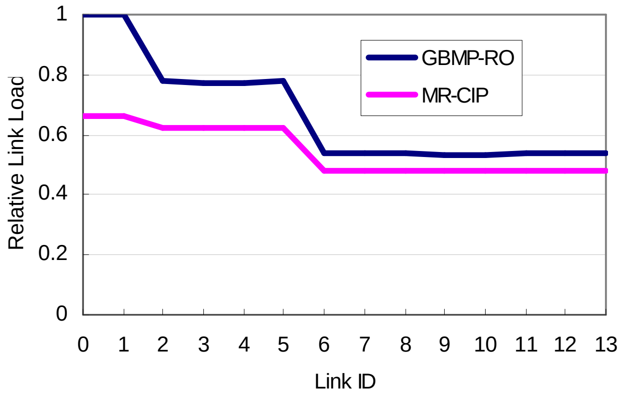

Figure 8. Related link load (Group size = 10)

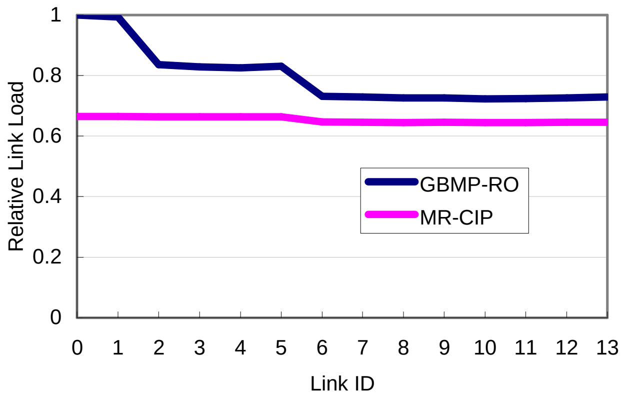

Figure 9. Related link load (Group size = 30)