Optimized Paging Cache Mappings for efficient location management
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Abstract—Cellular IP maintains distributed cache for location management and routing purposes. Distributed paging cache coarsely maintains the position of idle mobile hosts in a service area. Cellular IP uses this paging cache to quickly and efficiently find idle mobile. It can accommodate a large number of users attached to the network without overloading the location management system. Though paging caches may be put in a few selected nodes only, those are considerably large databases. More paging caches result in less paging load in exchange for increased hardware cost. In this paper we present Optimized Paging Cache Mappings for efficient location management. It reduces the size of the paging cache and the paging-update packets. It results in saving hardware cost.

Index Terms—Mobile IP, Cellular IP, HAWAII, Paging cache, Route cache, Mobile host

I. INTRODUCTION

Mobile IP, wireless LANs, protocol tunneling and mobility management are areas of growing interest these days. Mobile users roaming in foreign networks with their laptop or even smaller computers is a trend of the future. Roaming mobile users are willing to get the same services as they would get when attached to their office LAN using Ethernet and IP-protocol. In Mobile IP [1] packets addressed to a mobile host are delivered using regular IP routing to a temporary address assigned to a mobile host at its actual point of attachment. This approach results in a simple and scalable scheme that offers global mobility. Mobile IP is not appropriate, however, for seamless mobility in local areas. So, with frequent handoff micro-mobility protocols (Cellular IP[4], HAWAII[2]) have been proposed to handle local movement of mobile hosts without interaction with the Mobile-IP-enabled Internet. It has the benefit of reducing delay and packet loss during handoff, and eliminating registration between mobile hosts and distant home agents when mobile hosts remain inside their local coverage areas. Currently, these protocols support the notion of seamless mobility, passive connectivity, or paging. The future wireless Internet will need to support these requirements in order to deliver service quality, minimize signaling, and scale to support hundreds of millions of subscribers.

In Cellular IP [4, 6, 7, 8], a micro-mobility protocol, location management and handoff support are integrated with routing. To minimize control messaging, regular data packets transmitted by mobile hosts are used to establish host location information. Uplink packets are routed from a mobile host to a gateway on a hop-by-hop basis. The path taken by these packets is cached in intermediate nodes. To route downlink packets addressed to a mobile host, the path used by recently transmitted packets from the mobile host is reversed. When the mobile host has no data to send then it transmits ICMP IP packets called route-updates to the gateway to maintain its downlink routing soft-state. The principle of passive connectivity commonly found in cellular systems. In order to route packets to idle hosts a cellular IP mechanism called paging is used. Cellular IP uses two parallel cache systems to store the information related to the location of mobile hosts. The two systems basically operate in the same way. For idle mobile hosts exact location tracking is less important, instead, minimizing communication to save battery is of higher priority. By deploying two caches, the granularity of location tracking can be different for idle and active mobile hosts. Separating the location tracking for idle and active mobile hosts also improves the performance. Supposing there is just one set of cache, for each downlink packet the entire cache must be searched to find the destination mobile host. It is expected, however, that only a portion of the hosts will be in active state at any given time and that most of the packets are destined for active mobile hosts. Thus by separating the caches for active and idle mobile hosts only a smaller cache needs to be searched for most of the packets. It results in faster lookups and better scalability. Paging caches, which are considerably large databases, may be put in a few selected nodes only. More paging caches result in less paging load in exchange for increased hardware cost. Paging-update packets, however, are frequently generated for location management.

In this paper we present Optimized Paging Cache Mappings for efficient location management in Cellular IP networks (OPCMCIP).

II. LOCATION MANAGEMENT OF CELLULAR IP

A Cellular IP Network consists of interconnected Cellular IP nodes. They route IP packets inside the Cellular IP. A Cellular IP node that has a wireless interface is called a base station. A
Cellular IP node that is connected to a regular IP network by at least one of its interfaces is called a Cellular IP gateway. (as Figure 1.) The Cellular IP nodes are built on a regular IP forwarding engine with the exception that IP routing is replaced by Cellular IP routing and location management.

![Cellular IP Access Network](image)

**Figure 1. A Cellular IP Access Network**

The Cellular IP gateway is similar to the foreign agent of Mobile IP except for Cellular IP routing function. The Cellular IP gateway periodically broadcasts a beacon packet that is flooded in the access network. Cellular IP nodes record the neighbor they last received the beacon (include paging area identifier, Cellular IP network identifier and the IP address of the gateway) from and use it to route packets toward the gateway.

In addition, each Cellular IP node maintains a routing cache. When a data packet originated by a mobile host enters a base station, the local routing cache stores the IP address of the source mobile host and the neighbor from which the packet entered node. This soft-state mapping remains valid for a system-specific time called route-time-out. Data packets are used to maintain its routing cache mapping even though it is not regularly transmitting data packet. Therefore to keep its routing cache mappings valid, the mobile host transmits route-update packets on the uplink at regular intervals called route-update time. These packets are special ICMP packets addressed to the gateway. Typically, fixed hosts connected to the Internet remain online for extended periods of time, even though most of the time they do not communicate hence such hosts are excluded from routing cache, Cellular IP gateway broadcast in their domain to find a host. This action incurs large overhead. Therefore Cellular IP uses a paging technique. Cellular IP node does not only have a routing cache but also a paging cache. Paging cache mapping has a longer timeout period called paging-timeout hence a longer interval exists between consecutive paging-update packets. In order to remain reachable, mobile hosts transmit paging-update packets at regular interval defined by a paging-update-time. In addition, any packet sent by mobile hosts, including route-update packets, can update paging cache. However, paging-update packets cannot update routing cache. After migration the host always sends a paging-update packet to a new base station. Then the frequency of paging-update packets can be low without expired the timer. It is then ideal to set this frequency approximately equal to the migration frequency. The paging-update packet rate is the primary means of tuning Cellular IP mobility management according to a system’s cell size and average user speed. The performance is also sensitive to the route cache timeout. It should be set so that a mobile in soft handoff receives a few consecutive packets from both base stations to ensure seamless handoff. A longer route cache timeout may occur waste of resources. The route-update packet repetition rate should be such that a few route-update packets arrive during a route cache timeout to maintain the mappings even if some route-update packets get lost.

The separation of paging and routing has a further advantage. A wireless access network can have a large number of mobile hosts attached to it at a time, only a small percentage of which are receiving data packets. In this case, paging cache will contain a large number of host mappings at any time, making it a considerably larger database than routing cache. As paging caches are only used to search for mobile hosts, and not to route high bit rate data, the network operator can choose to place paging caches in only a small number of well positioned nodes and let other nodes broadcast search messages. By creating more paging caches, the location information can be made more precise thus reducing the size of the searched area.

**III. PROPOSED SCHEME**

In this paper, we present Optimized Paging Cache Mappings for efficient location management in Cellular IP networks (OPCMCIP). Paging cache mappings are different from regular Cellular IP mappings. They map paging area identifiers to node ports. But, regular Cellular IP mappings map mobile host identifiers to node ports. Paging area identifiers instead of mobile host identifier are recorded in each node’s paging cache on the created a hop-by-hop reverse path (downlink path). The mobile hosts in the same paging area are grouped into a paging area identifier. All mobile hosts in the same paging area share the mapping in the paging cache. So, the size of the paging cache is reduced and network traffic is decreased due to reducing paging-update packets. Also, since the hardware cost of the paging cache is decreased, more nodes can be installed the paging caches in Cellular IP networks.

Cellular IP allows idle mobile hosts to roam large geographic areas without the need to transmit location update packets at cell borders. The network operator can group the cells into paging areas, each comprising an arbitrary number of (typically adjacent) cells. Each paging area has a unique identifier in the given Cellular IP network. Each base station transmits its paging area identifier in its periodic beacon signals, thus enabling mobile hosts to notice when they move into a new paging area.

The three types of control packets (paging-update, route-update and paging) used by Cellular IP can be regular IP packets. All
three types contain the mobile host’s identifier. As this is
dicated in the source or destination field of the packet (for
paging-update/route-update and paging packets, respectively),
the payload can remain empty. But, all control packets include
a paging area identifier for paging area notification. (From MH
to nodes) Each node monitors this information for paging. The
control packets can be implemented by a new IP option that
need not be understood by regular routers since these packets
never leave the access network (Cellular IP network).

An idle mobile host that moves into a new paging area must
transmit a paging-update packet. Paging-update packets are
routed from the base station to the gateway using hop-by-hop
routing. Selected nodes of the Cellular IP network are equipped
with paging cache. These nodes monitor passing paging-update
packets and update paging cache mappings to point toward the
new paging area. Paging-update packets reach the gateway and
are discarded to isolate Cellular IP specific operations from the
Internet. When the mobile host moves within a paging area, it
transmits a paging-update packet only when the system specific
time, paging-update-time expires. Outdated mappings of
paging caches are cleared if no update arrives before paging-timeout expires. When an IP packet arrives at a Cellular
IP node, addressed to a mobile host for which no up-to-date
route cache mapping is available, the paging cache is used to
route the packet. If the node has no paging cache, it forwards
the packet to all downlink neighbors. A node that has paging
cache but has no mapping in it for the destination mobile host
discards the packet.

A packet arriving to the node from one of the downlink
neighbors is assumed to be coming from a mobile host. The
packet is first used to update the node's route and paging caches
and is then forwarded to the node's uplink neighbor. To update
the caches, the node reads the packet type, port number, the
source IP address and paging area identifier. Pacing-update
packets update the paging cache only. Route-update packets
update both route and paging caches. Data packets only refresh
the soft state of both caches, but do not change it.

Above location management is similar to regular Cellular IP
except for paging cache mappings. But, route cache mapping is
equal to cache mapping of regular Cellular IP. Modified paging
cache consists of

{ PA_ID, interface, MAC address, expiration time, timestamp }

The PA_ID instead of the source IP address is the identifier of
the paging area the mapping corresponds to. The interface and
the MAC address denote the downlink neighbor toward the
paging area that includes the mobile host. The timestamp field
contains the timestamp of the control packet that has
established the mapping. When a data packet arrives from a
downlink neighbor, the route cache entry of the source IP
address is searched first. If the data packet is coming from the
same neighbor as indicated by the cache entry then it is sent
from the direction where the mobile host was last seen. In that
case the mapping is only refreshed: the expiration time is set to
the current time + route-timeout. If the node has paging cache,
the expiration time of the mapping in the paging cache is set to
current time + paging-timeout as well. Then the packet is
forwarded uplink. If the data packet arrived from a different
neighbor that is in its mapping or no mapping exists for the
PA_ID, then the packet is dropped. When an update packet
arrives from a downlink neighbor then the authentication is
validated first. Packets with invalid authentication must be
dropped and the event should be logged as a potential
tampering attempt. For valid packets the node creates the
following entry that is equal to cache mapping of regular Cellular IP:

{ the newly arrived packet's source IP address,
  the interface through which it arrived,
  the source MAC address of the arrived packet,
  current time + route-timeout,
  the timestamp in the arrived update packet }

This mapping is used to update route cache, if the incoming
packet is a route-update packet. If a valid mapping for the
source IP address already exists, then it is replaced by the new
entry and the timestamp is updated, otherwise the packet is
dropped. If no mapping exists for the source IP address then
the mapping is added to the route cache. The paging cache is
updated in the same way, but using paging-timeout instead of
route-timeout and different mapping format. If the node has no
paging cache then only the route cache is updated. If the
incoming packet is a paging-update, then only the paging cache
is updated (if any). If the packet is a paging-teardown packet
and the authentication information is valid, then mappings of
the mobile host with timestamp earlier than the timestamp of
the packet are removed from both the route and the paging
cache. After cache modifications the control packet is
forwarded to the uplink neighbor. Similarly, The gateway
router has both route-update cache and paging-update cache.
But, paging cache of the gateway router is different from
format of general CIP nodes. The gateway router must identify
the destination IP address of received packets (from the
Internet) and inform downlink nodes about paging area
identifier of the destination IP address. So, the destination
address and the paging area identifier of received packets (these
mappings) are included in the paging cache.

A packet arriving to a Cellular IP node from the uplink
neighbor is assumed to be addressed to a mobile host. The node
first checks if the destination IP address has a valid mapping in
the route cache. If such a mapping exists, the packet is
forwarded to the downlink neighbor found in the mapping. If
the route cache contains no mapping for the destination IP
address and the node has no paging cache, then the packet is
broadcast on all interfaces of the node except the interface of
the uplink neighbor. If the node has paging cache and there is a
mapping for the destination paging area identifier, then the
packet is forwarded to the neighbor found in that mapping. If
the node has paging cache, but there is no mapping for the
destination paging area identifier, then the packet is dropped.
Both caches have each timer for simplicity and mobility of
mobile hosts. These timers are important in Cellular IP
networks for efficiency. The repetition rates of paging-update
and route-update packets must be carefully selected for high
performance. For both timeouts, a higher value results in less
frequent control messages, but it extends the validity of unused
paths. Otherwise, a lower value results in more frequent control messages, but it considerably loads the network. Especially, paging-update packets are proportional to attached mobile hosts. One mapping entry in the paging cache covers all mobile hosts in the same paging area. One entry (paging area mapping) in the paging cache is refreshed even if at least one mobile host in the same paging area sends the route-update packet. So, paging cache refresh time by mobile hosts can be lengthened, and then the number of paging-update packets is reduced. Finally, network load is decreased.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed scheme using the ns simulator [9]. We compare our scheme with regular Cellular IP. The simulation topology used for the reported results is shown in Figure 2. The assumption of the Cellular IP ns simulation environment is an “ideal wireless interface” (no delay, bit error or loss congestion over the wireless interface). The design goal of the proposed scheme is to operate efficiently under the small size of the paging cache. In accordance with this design goal, the proposed scheme (OPCMCIP) optimizes the paging cache mappings.

The figure 4 represents TCP sequence numbers at the correspondent host (CH) for packets against time in seconds. From the simulation results we observe that the performance of our scheme (OPCMCIP) is similar to regular Cellular IP. Although our scheme has the small size of the paging cache (1 entry), its performance is similar to regular Cellular IP (10-entry). This optimizing effect is increased in networks with a large number of nodes and mobile hosts.
paging-update packets. So, it results in saving hardware cost and reducing network load.

We expect that the proposed scheme will contribute to design the IP-based Cellular networks effectively. Further research is required to manage multiple base stations without paging cache efficiently in the same paging areas.

REFERENCES