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Mobility Management in Wireless Cellular Networks Using Other Nodes as Relays

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ABSTRACT

In this paper, we propose a handover protocol called CAMP in wireless cellular networks. When a mobile user is not in the communication range of base stations, this protocol utilizes other users to make a virtual tunnel between the user and a base station. In this way, the user can communicate data with a base station from far distances. We also propose a handover protocol called MCAMP. This protocol uses two virtual tunnels between the user and base stations. In this way, the communication gets robust against both the probable disconnection during handover and tunnel failure. We have simulated these protocols. Our simulations show that the CAMP protocol reduces user's disconnection duration using the tunneling method with acceptable overhead. Consequently, packet loss rate and end-to-end delay are reduced. Then, MCAMP improves CAMP in terms of connection stability, packet loss rate, and end-to-end delay.

Keywords: Cellular network, Ad Hoc network, Handover, Mobility, Routing

Introduction

The existing protocols (such as [1, 2, 3, 4 5]) consider the case for handover in which the mobile node (MN) is inside the communication range of a base station (BS) and is entering the communication range of another BS. In these protocols, when MN is not the communication range of any BS (as in Fig. 1), it loses its connection. In this study, we want to design a new handover protocol with the following new features compared to the existing protocols (reviewed in Section II):

- Other users are used as relays between mobile nodes and BSs.
- The tunnel between MN and BS may consist of multiple relay nodes.
- Relay nodes can also forward data packets to/from the MN.

The rest of this paper is organized as follows. We review related works in Section II. We propose CAMP in Section III. We propose MCAMP in Section IV. Section V contains our simulation results and Section VI concludes the paper.

Related Work

In this section, we review existing researches related to our work.

There are a number of researches [6] so far in integrating IP mobility protocols and mobile Ad Hoc networks. A qualitative comparison of the routing solutions for integration is presented.

ANHOA [7] can assist MNs' handoffs by utilizing the self-organizing small scale Ad Hoc networks. Better handoff choice can be made when there are multi-hop handoff alternatives. Moreover, with multi-hop connections, multiple cells can balance the traffic load and collaboratively serve users with better performance.

In [8], authors introduce the integration of Ad-Hoc networks in the mobility architecture of the IST Daidalos II project. It focuses on the mobility architecture of ad-hoc networks and the movement of nodes, while still providing them with the infrastructured features. To help accomplish this goal, concepts like the IEEE 802.21 and NetLMM are used and extended to support and integrate mobility in mobile ad-hoc networks.

In [9], authors present an analytical framework based

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on the concept of Relay Path Set. This model can be used to describe, compare the different strategies for integrating mobile Ad Hoc networks and the Internet, propose new strategies and improve the existing strategies at different module levels.

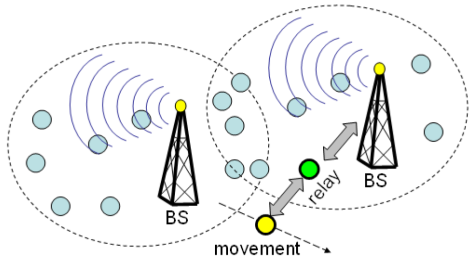

Figure 1. Network Model

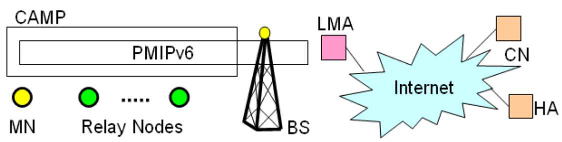

Figure 2. Relation of PMIPv6 and CAMP

The CAMP Protocol

In this section, we propose a handover protocol that uses other users to relay packets between the mobile node and base stations. Our proposed protocol is called CAMP (Cooperative Ad Hoc Mobility Protocol).

When MN is in the communication range of a base station, it communicates directly with the station and does the handover process according to PMIPv6. When MN is not in the range of any station, it utilizes other fixed/mobile users to create a virtual tunnel (Fig. 2) to a base station and then does the handover process according to the PMIPv6 protocol. After registering in the base station and the Layer-3 handover, MN uses the tunnel to send or receive data to/from the base station. PMIPv6 manages Layer-3 handover whereas CAMP manages the connection between MN and the base station using relay nodes. The two protocols can be used together to increase network coverage and reduce handover problems.

Tunneling Protocol

There are a number of protocols [10] for creating and maintaining virtual tunnels which can be used in CAMP.

Routing and Gateway Discovery

There are a number protocols [11, 12] proposed for routing in wireless Ad Hoc network and identifying one or more users as gateways to the outside of the Ad Hoc network. One of them can be used in the CAMP protocol.

Addressing

When MN registers in a BS, it receives a COA from the BS which is in the IP address rage of that BS. This is the case in both direct and tunneled communication with the BS.

Handover Time

In CAMP, MN must perform handover in the following cases.
- MN is getting out of the communication range of BS or tunnel.
- The tunnel is broken due to events such as node movement or node failure.
Then, MN has to register with a BS or a node that can provide tunnel to a BS.

Handover Process

We design the handover process in CAMP with regard to the situation in which MN is, as follows:

Switching between two BSs

The handover process is the same as the PMIPv6 protocol without creating any tunnel.

Switching from a BS to a relay node to tunnel to the same BS

MN creates a virtual tunnel between MN and the BS using the relay node and then continues communication with the BS without running PMIPv6. In this case, MN does not get a new COA and does not inform HA of this new tunnel.

Switching from a BS to a relay node to tunnel to another BS

MN creates a virtual tunnel between MN and the new BS using the relay node and then runs PMIPv6 to do handover between the two BSs. In this case, MN gets a new COA from the new BS.

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Switching from a relay node to a BS to which MN has tunnel

First, MN runs Layer-2 handover to register with the BS. MN releases the tunnel between MN and the BS and then continues communication with the BS directly without running PMIPv6. In this case, MN does not get a new COA and does not inform HA of this new connection.

Switching from a relay node to a BS to which MN has not tunnel

First, MN runs Layer-2 handover to register with the new BS. Then, MN runs PMIPv6 to do handover between the two BSs. In this case, MN gets a new COA from the new BS. Then, MN releases the tunnel between MN and the old BS and then starts communication with the new BS directly.

Switching between two relay nodes to tunnel to the same BS

MN creates a new tunnel between MN and the BS using the new relay node. Then, MN releases the old tunnel and continues communication with the BS without running PMIPv6. In this case, MN does not get a new COA and does not inform HA of this new tunnel.

Switching between two relay nodes to tunnel to different BSs

MN creates a new tunnel between MN and the new BS using the new relay node and then runs PMIPv6 to do handover between the two BSs. In this case, MN gets a new COA from the new BS. Then, MN releases the old tunnel and continues communication with the new BS through the new tunnel.

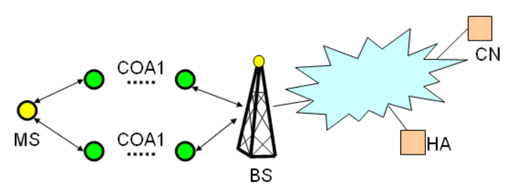
Path Selection Priority

When moving, MN periodically measures potential connections to relay nodes and BSs. If the current connection is being lost and it needs to do handover, MN chooses a new connection according to the following priorities.

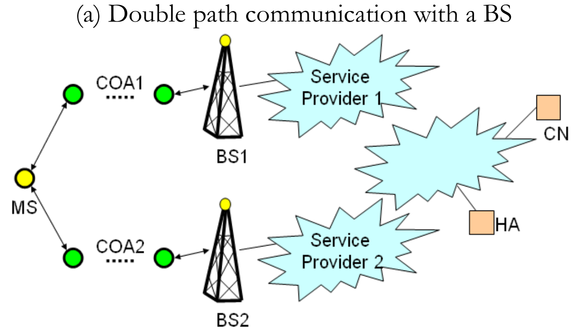
1. Direct connection to the current BS (highest priority)
2. Connection to the current BS through relay nodes
3. Direct connection to a new BS
4. Connection to a new BS through relay nodes (lowest priority)

The MCAMP Protocol

We practically have the following cases of MN disconnection in CAMP.
- Relay nodes can be unstable. It emerges that the tunnel becomes unstable.
- MN may experience disconnection from BSs during handover. This is because of the facts that the MN connection to the previous BS is weak during handover and Layer-3 registration with the new BS takes considerable time (more than one second [3, 4]).
To increase connection stability, our idea is that MN keeps two disjoint tunnels to BSs and data are distributed among the two tunnels. Then, when one tunnel fails, or when the MN is doing handover on one tunnel, the other tunnel can be used without delay to avoid user disconnection. We call this protocol MCAMP (Multipath CAMP). Methods for finding disjoint paths in an Ad Hoc network are studied in [13] and [14].



(a) Double path communication with a BS



(b) Double path communication with HA

Figure 3. Two kinds of double path communication in MCAMP

Hereafter, we present MCAMP. If MN is connected directly to a BS, it does not keep a multipath connection. Multipath connection is used only when MN connects to BSs through relay nodes. We consider two kinds of multipath communication in MCAMP.

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MN tries to have the first kind, because it does not need to run Layer-3 handover.

- Both the tunnels are connected to the same BS: In this mode (Fig. 3(a)), the multipath connection is between MN and the BS. HA is not aware of being multipath. Both MN and the BS distribute traffic among the two tunnels. MN has one COA.
- The tunnels are connected to different BSs: In this mode (Fig. 3(b)), the multipath connection is between MN and HA. The BSs are not aware of being multipath. Both MN and HA distribute traffic among the two paths. MN has two COAs.

Addressing

When MN registers in a BS, it receives a new COA from the BS which is in the IP address rage of that BS. MN receives two COAs when connecting to two BSs. Having multiple COAs is possible according to the MCOA [12] standard.

Handover Process

We design the handover process in MCAMP with regard to the situation in which MN is, as follows:

Switching between two BSs

The handover process is the same as the PMIPv6 protocol without creating any tunnel.

Switching from a BS to two relay nodes where both the tunnels are connected to the old BS

1. MN requests to create both the tunnels.
2. When the first tunnel is ready, MN starts communication with the BS through that tunnel.
3. MN ends the direct Layer-2 connection to the BS.
4. When the second tunnel is ready, MN starts multipath communication with the BS through the two tunnels.

Switching from a BS to two relay nodes where only one of the tunnels is connected to the old BS

1. When the first tunnel is ready to the old BS, MN starts communication with the BS through that tunnel.
2. MN ends the direct Layer-2 connection to the old BS.
3. MN requests to create both the tunnels.
4. When the second tunnel is ready to the new BS, MN runs Layer-3 registration with the new BS according to PMIPv6.
5. MN starts multipath communication with HA through the two tunnels.

1. When the first tunnel is ready to the new BS, MN runs Layer-3 registration with the new BS according to PMIPv6.
2. MN starts single path communication with the new BS through the first tunnel.
3. MN ends the Layer-3 connection to the old BS according to PMIPv6.
4. MN ends the direct Layer-2 connection to the old BS.
5. When the second tunnel is ready to the new BS, MN starts multipath communication with the new BS through the two tunnels without running Layer-3 registration.

Switching from a BS to two relay nodes where the two tunnels are connected to different new BSs

1. MN requests to create both the tunnels.
2. When the first tunnel is ready to a new BS, MN runs Layer-3 registration with this new BS according to PMIPv6.
3. MN starts single path communication with the new BS through the first tunnel.
4. MN ends the Layer-3 connection to the old BS according to PMIPv6.
5. MN ends the direct Layer-2 connection to the old BS.
6. When the second tunnel is ready to the other new BS, MN runs Layer-3 registration with this new BS according to PMIPv6.
7. MN starts multipath communication with HA through the two BSs.

Switching from relay nodes to BS without changing BS

1. MN establishes a direct Layer-2 connection to the BS.
2. MN starts direct communication with the BS using the old COA.
3. MN releases the tunnels.

Switching from relay nodes to BS with changing BS

1. MN establishes a direct Layer-2 connection to the new BS.
2. MN runs Layer-3 registration with the new BS according to PMIPv6.
3. MN starts direct communication with the new BS using the new COA.
4. MN ends the Layer-3 connection to the old BS according to PMIPv6.
5. MN releases the tunnels.

Simulation

We implemented CAMP and MCAMP in the NS2.29 [14] network simulator. In this section, we evaluate the performance and the overhead of them. The following protocols are evaluated in our experiments:

- No-CAMP: the PMIPv6 protocol without node cooperation in relaying packets
- CAMP: the CAMP protocol with cooperation and using PMIPv6 for Layer-3 handover
- MCAMP: the MCAMP protocol with cooperation and using PMIPv6 for Layer-3 handover

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We used the PMIPv6 implementation developed in [13] and the NIST mobility package [14]. We used BonnMotion to generate appropriate mobility commands for NS2 to achieve the given node speed.
To evaluate the mentioned protocols, we define a simulation scenario presented in Table I. In this scenario, we use different values for average MN's speed in different executions whereas the other parameters are fixed to evaluate the performance of the protocols under different mobility levels.

Table 1
Simulation Parameters

Parameter	Value
Number of Relay Nodes	400
Network Topology	Uniformly Distributed
Network Traffic	A Constant-Bit-Rate flow from CN to MN with rate 100 Kbps
Layer-3 Handover Protocol	PMIPv6
Ad Hoc Routing Algorithm	AODV [20]
Node Switching Delay	30 ms
MN's Mobility Model	Manhattan Grid [19]
Relay's Mobility Model	Random Way Point [19]
Simulation Duration	1 hour

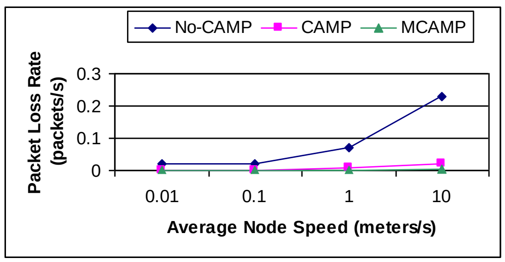

Figure 4. Packet loss ratio versus average node speed

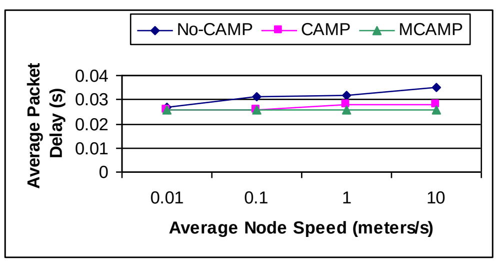

Figure 5. Average packet delay versus average node speed

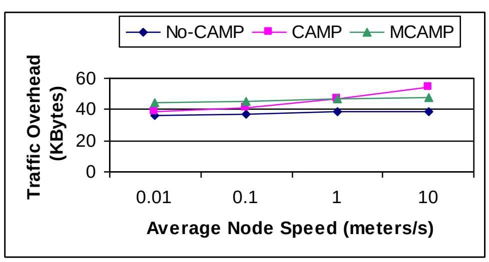

Figure 6. Traffic overhead versus average node speed

Simulation Results

Fig. 4 shows CAMP/MCAMP's ability in correctly delivering packets to destination under different mobility conditions. With increase in node speed, there are more times in which MN is located out of BS's communication range. In those times, No-CAMP cannot stop MN's disconnection without using relays. Thus, MN experiences packet loss. The CAMP protocol utilizes relay nodes to keep MN connected as long as possible. In our experiment, CAMP is able to

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reduce packet loss rate averagely by 310 percent compared to No-CAMP.

To reduce packet losses, MCAMP tries to minimize the disconnection duration due to handover. MCAMP achieves this goal by utilizing two disjoint tunnels, because MN uses the other tunnel when a tunnel fails. This reduces end-to-end packet delay too. With increase in node speed in Fig. 4, MN faces more handovers and thus faces more disconnection. For this reason, packet loss is more likely to happen in CAMP. In our experiment, MCAMP is able to reduce packet loss rate averagely by 240 percent compared to CAMP.

Fig. 5 shows average packet delay in our experiment. When MN is disconnected, packets are either dropped or delayed by staying in other nodes. Dropped packets have to be retransmitted and therefore experience delay. In our experiment, CAMP is able to reduce end-to-end packet delay averagely by 14 percent compared to No-CAMP.

When a tunnel fails in MCAMP, packets are immediately transmitted through the other tunnel. In our experiment, MCAMP is able to reduce end-to-end packet delay averagely by 17 percent compared to CAMP.

Fig. 6 shows CAMP/MCAMP's traffic overhead under different node speeds. CAMP and MCAMP create more overhead than No-CAMP due to the use of relay routes. But CAMP/MCAMP's overhead is acceptable with respect to the reduction in packet loss rate and the improvement in connection stability.

Conclusion

We propose a handover protocol called CAMP in wireless cellular networks. When a MN is not in the communication range of BSs, this protocol utilizes other users to make a virtual tunnel between the MN and a BS. In this way, the MN can communicate data with a BS from far distances.

We also propose MCAMP by improving CAMP to use multiple tunnels. When a MN is not in the communication range of BSs, this protocol utilizes other users to make two virtual tunnels between the MN and BSs. In this way, the communication gets robust against both the probable disconnection during handover and tunnel failure.

In our simulation experiments, we have:

- CAMP is able to reduce packet loss rate averagely by 310 percent compared to No-CAMP.
- MCAMP is able to reduce packet loss rate averagely by 240 percent compared to CAMP.
- CAMP is able to reduce end-to-end packet delay averagely by 14 percent compared to No-CAMP.
- MCAMP is able to reduce end-to-end packet delay averagely by 17 percent compared to CAMP.
- CAMP/MCAMP's overhead is acceptable with respect to the reduction in packet loss rate and the improvement in connection stability.

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