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IP Mobility and the CDMA Radio Access Network: Applicability Statement for Soft Handoff

Status of this Memo

This document is an individual contribution for consideration by the Mobile IP Working Group of the Internet Engineering Task Force.

Distribution of this memo is unlimited.

Abstract

Recently, there have been a variety of proposals submitted to the Mobile IP Working Group and to other IETF working groups for IP mobility solutions that seek to enhance or replace mobile IP. These proposals, often characterized as micromobility or fast handoff, are addressed primarily at the perceived need of multimedia sessions such as video or voice over IP for faster handoff between radio base stations, and are primarily directed at real time multimedia traffic in 3rd generation cellular access networks. In this paper, we discuss the design of CDMA radio access networks (RANs) and the applicability of IP mobility to soft handoff in a CDMA RAN. We attempt to show that given current IP routing algorithms and the constraints on a CDMA RAN, IP mobility solutions have little, if any, role to play in handoff within the RAN. In contrast, an IP mobility solution is likely to play a big role in fast handoff between RANs, also called hard handoff. While future developments in IP networking may change this situation, IP mobility in CDMA networks currently seems to apply only when the mobile node roams between disconnected RANs rather than between base stations within a RAN or between connected RANs.

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1.0 Introduction

Mobile IP [1] allows IP hosts that change their point of attachment to the network to keep their IP address as they change from their home subnet to other subnets. Recently, there have been a variety of proposals advanced for augmenting or replacing mobile IP in access networks for cellular telephony systems. These proposals are often characterized as supporting micromobility or fast handoff, and are directed towards real time multimedia streams in 3rd generation cellular networks (see [2] [3] [4] [5] and [7]).

While these proposals may have some applicability if handoff between disconnected RANs is very frequent, their utility is lessened in the presence of RAN mobility like that offered by today's TDMA and CDMA systems. In fact if the RAN protocols offer transparent mobility throughout a given domain of interconnected RANs, these proposals do not contribute anything since they are essentially intra-domain mobility management protocols. As cellular networks evolve towards more pervasive IP technologies, host mobility within these networks must accommodate some level of movement of IP traffic.

In this paper, we discuss CDMA radio access networks and why current IP mobility solutions (including mobile IP) are not applicable to soft handoff in a CDMA RAN. In effect, the CDMA RAN network with soft handoff is a mobility mechanism transparent to L3 and above on the mobile terminal and its corresponding host, similar to but not identical with the mechanisms used for interaccess point mobility in wireless LAN technologies such as IEEE 802.11 [8]. It is therefore not an appropriate candidate for moving into the network layer given current IP routing algorithms. In contrast, IP mobility solutions that are directed at improving handoff performance within the core network, often called hard handoff, are likely to play an important role in enhancing the performance of IP networking for CDMA (see [6] for an example).

2.0 Terminology

mobile terminal
A mobile IP host. In mobile IP terminology, this is called the mobile node.

base station
A fixed, land-based radio transmitter and receiver, used to provide cellular telephony radio coverage in a limited geographic area. A mobile terminal may be in contact with one or more base stations at a time in CDMA networks. Also called the Base Transceiver Station (BTS) or Node B.

RAN
The radio access network. This is a wired network that sits between a collection of base stations and the core, wired telephone network. The RAN in CDMA systems is involved in real-time distribution and collection of physical layer radio frames to and from base stations, a topic that is discussed in the next section.

soft handoff
The process by which a moving CDMA mobile terminal is transferred between one base station or set of base stations to another within the radio access network. Soft handoff is typically very fast (on the order of 20 ms) and has a low probability of dropping ongoing real time connections.

hard handoff

The process by which a moving mobile terminal is transferred between one cellular service provider's network and another or between two RANs that do not share a direct connection within a provider's network. Hard handoffs have a higher probability of connection droppage, and are slower (usually 100 ms or more).

macrodiversity

A term used to describe the fact that within the CDMA RAN, there is no single octet stream corresponding to the data that arrives at or is sent by the mobile terminal. Macrodiversity results because the mobile terminal can be in contact with more than one base station at a time.

frame selector

A combination software/hardware unit at the gateway to the RAN that combines the multiple octet streams from multiple base stations in contact with a single mobile terminal into a single octet stream. A similar process happens at the mobile terminal. Also called the macrodiversity combiner or Selection and Distribution Unit (SDU).

RAN gateway

A functional unit positioned between the RAN and the core network. The RAN gateway includes the frame selector, in addition to functional units that perform soft handoff and radio frame processing. Also called the Base Station Controller (BSC) or Radio Network Controller (RNC).

radio frame

A short (usually 20 millisecond) unit of transmission at the physical radio layer used to transmit data over the air to and from the mobile terminal. The frames do not usually contain complete IP packets as sent or received by applications on the mobile terminal, but rather contain small sections of octet stream data that must be framed by a higher layer protocol (such as PPP) to form IP packets. On a basic fundamental data rate channel one radio frame contains about 20 octets. Radio frames may be retransmitted a small number of times to increase the reliability of the octet stream transport. This is performed by a negative- acknowledgement protocol known as the Radio Link Protocol (RLP).

3.0 RAN Architecture and Characteristics

A RAN consists of a RAN gateway connected to one or more base stations. In the network to mobile terminal (forward) direction, the RAN gateway performs the following functions:

1) Receive packets from the core network destined to the mobile terminal,

2) Process those packets into radio frames,

3) Replicate the radio frames and transmit copies to base stations that are currently in contact with the mobile terminal in a way such that the frames arrive at each base station in a timely fashion,

4) Manage the retransmission of individual radio frames when negative acknowledgements are received.

In the mobile terminal to network (reverse) direction, the RAN gateway performs the following functions:

1) Collect copies of the radio frames fowarded by base stations that are currently in contact with the mobile terminal,

2) Combine these (possibly errorful) copies into one (hopefully error-free) radio frame using some algorithm,

3) From the resulting radio frame stream, synthesize an outgoing octet stream of packets for the core network.

In both directions, the RAN gateway performs the following function:

1) Manage the power with which mobile nodes and base stations are transmitting, so as to maintain a low error rate while at the same time minimizing the transmitted power and therefore interference among different transmitters (and drain on the mobile terminal's battery).

2) In concert with the mobile terminal, manage the set of base stations with which a mobile terminal is in contact such that the

quality of the radio signal is maintained as the mobile terminal moves.

The use of multiple base stations to transmit and receive the same radio frames to and from the mobile node at the same time is known as "macrodiversity" and can help to improve the reliability of the wireless link. Note that some of the base stations may be owned by a neighboring RAN and this necessitates a RAN-to-RAN interface to carry the radio frames.

The following figure illustrates the architecture and how the CDMA
RAN network works:

```
                         Core Network

                            ^
                            |   incoming/outgoing octet stream
                            |    from/to corresponding node
                            |        (e.g. 129.142.68.79)
                            v
   +-----------------------------------------------------+
   | RAN Gateway                                         |
   |                                                     |
   |    +-------------+  +-----------+  +----------+     |
   |    |             |  |           |  |          |     |
   |    | Frame       |  | Frame     |  | Soft     |     |----------->
   |    | Selection   |  | Splitting |  | Handoff  |     |       to another
   |    |             |  |           |  | Control  |     |       RAN Gateway
   |    +-------------+  +-----------+  +----------+     |       in neighboring
   |                                                     |       RAN
   |    +---------------+                                |
   |    |               |                                |
   |    | Radio Frame   |                                |
   |    | Processing    |                                |
   |    |               |                                |
   |    +---------------+                                |
   |                                                     |
   +-----------------------------------------------------+
            |             |              |            |    *
            |             |              |            |      *
            |             |     ...      |            |       * radio
            |             |              |            |       * frames
            |             |              |            |      *
            |             |              |            |    *
       +---------+   +---------+   +---------+   +---------+
       | Base    |   | Base    |   | Base    |   | Base    |
       | Station |   | Station |   | Station |   | Station |
       |   B1    |   |   B2    |   |  B42    |   |   B43   |
       +---------+   +---------+   +---------+   +---------+
            \              |
             \             V
              \--------->
```

```
                               |
                             -----
                            /     \
                        -----       -----           162.42.42.42
```

```
                  | mobile terminal|(  --->
                  ------------------
                    ( )        ( )
```

The links between the RAN gateway and the base stations are typically point to point links today, though provisions exist in the 3rd generation standards for switched networks.

In the above figure, a mobile terminal with IP address 162.42.42.42 is corresponding with a host having the IP address 129.142.68.79, through a CDMA cellular network. The mobile terminal is in contact with two base stations, B1 and B2. The RAN gateway takes incoming packets from 129.142.68.79 and splits them into two streams that it sends to base stations B1 and B2. A mobile terminal can be in communication with up to 3 and, in some CDMA systems, up to 6 base stations at a time. When the multiple octet streams are received at the mobile terminal, the mobile terminal performs a sophisticated combination of the multiple packet streams at L1 to deliver the end packet to the application.

Packets flowing in the other direction, from 162.42.42.42 to 129.142.68.79, are put into an octet stream which is then divided into radio frames. Each radio frame is received by B1 and B2 and delivered to the frame selector in the RAN gateway. The frame selector performs signal processing on the incoming radio frames and produces a single frame that is then sent to the re-sequencing buffer where the octet stream is re-created. The IP packets are formed from the octet stream and transmitted into the core IP network.

An important point to note about the RAN is that, even if the RAN itself is running IP, routing in the RAN does not use the mobile's IP address. In fact, the IP packets sent by the mobile terminal are not tunneled through the RAN nor do they necessarily appear in a form that would be recognizable using a packet sniffer. The packets in the RAN contain radio frames that have been highly processed into a form that is extremely efficient for the base stations to handle and that efficiently uses radio spectrum, including compensations for the inherently lossy nature of the radio medium.

On the forward leg to the mobile terminal, because the delay and jitter constraints between multiple base stations transmitting to the same mobile terminal are so tight (5ms to 80ms), the RAN gateway essentially puts out streams of radio frames that the base station can quickly pull off the wire and transmit over the air. On the reverse leg from the mobile terminal, the base station simply pulls the radio frames off the air and puts them on the wire without any further processing. The RAN gateway's radio frame processor is responsible for making sure that the jitter and delay constraints are met, and for processing packets from the core network into radio frames.

When the mobile terminal begins to move out of range of stations B1 and B2, the RAN gateway adds and deletes base stations from the set currently serving the mobile node. This process is called soft handoff. Note that new base stations may belong to a connected neighboring RAN which requires closely-coupled RAN-to-RAN interaction. The real time constraints on soft handoff are extremely tight. All base stations involved in soft handoff must transmit the command for the mobile to move at the same time. North American cellular networks use the Global Positioning System as a time source to assure that these timing constraints are met.

As shown in the figure, two RAN gateways can be connected together through a direct link. This link allows radio frames containing data and RAN control protocol to flow between two RANs. As a result, two RANs can perform soft handoff between them, increasing the quality and reliability of the connection when a user moves between coverage areas. A RAN gateway and its collection of base stations can only cover a limited geographic area, so RAN interconnection is very important in cellular networks for maintaining good connection quality over large geographic areas.

4.0 Applicability of IP Mobility to Soft Handoff

Most of the proposals for IP mobility in the RAN assume the following:

1) An end-to-end IP routing model for routing through the RAN.

2) A one-to-one mapping between the mobile terminal and the base station with which it is in contact.

3) The IP packets coming from the mobile terminal are transported directly on L2 in the RAN.

As the above discussion has attempted to show, the extremely tight real time constraints on traffic in the RAN require that RAN traffic be highly processed as radio frames for efficient delivery into and from the radio medium by the base stations. This precludes routing IP packets from the mobile directly over the RAN. Furthermore, because there are multiple octet streams flowing over the RAN that correspond to one logical octet stream going to and from the mobile terminal, there is no one-to-one mapping between the mobile terminal and a base station.

Taking mobile IP as an example, using mobile IP in the RAN would require that a mobile IP foreign agent (FA) be present at each base station. However, because the mobile terminal can be in contact with up to 6 base stations at once, there is no unique care-of address for the mobile (unless the mobile uses a co-located care-of address). Therefore, the home agent (HA) would need to forward packets to multiple FAs. Furthermore, on the reverse leg, a frame selector is still necessary to generate a single packet for the corresponding node.

In effect, the RAN controller is an application level transport and mobility mechanism specialized to the CDMA radio medium. An application's packets to/from the mobile effectively run over a "stratified stack" in the RAN, in which the bottom stratum is the RAN protocol stack, and the upper stratum is the IP stack on the mobile terminal and corresponding node. The RAN controller is therefore not a good candidate for replacing with current network level mobility mechanisms. Because of the hard real time constraints involved in soft handoff, the RAN controller's soft handoff function is also not a good candidate for replacing with more general application level mechanisms, such as SIP [4].

5.0 Applicability of IP Mobility to Hard Handoff

Note that the above considerations do not apply to hard handoff, which occurs outside of the RAN. When a mobile terminal moves between two RANs that are not interconnected, the RAN controller defers handoff to the core network. Some mechanism is necessary in the core network to move the mobile terminal's point of attachement at the network level. IP mobility solutions for fast handoff are applicable here.

Proposals such as [6] that apply after frame selection do not involve soft handoff and therefore are appropriate for implementing fast, hard handoff.

6.0 Future Prospects for IP Mobility in the CDMA RAN

What would it take to enable IP mobility in the RAN? The question is worth examining because the end-to-end model of networking which would be required to make IP mobility work in the RAN has attractions from the point of view of simplicity of network management and transparency.

Certainly, routing the mobile's packets directly in the RAN would be a major contributor. For that to happen, IP over the air interface would be necessary. The major impediment to IP over the air is currently header size, but new work in header compression may eliminate this objection. Given that a spectrally efficient representation of IP on the radio medium is possible, IP packets can be sent out over the air by the mobile terminal, and the base stations can handle the packets precisely as they currently do with the specialized radio frames. The result would be that IP packets from the radio would appear directly on L2 in the RAN, rather than in a stratified stack.

However, there is still a problem with the multipath nature of macrodiversity. On the forward leg, the routing from a single source at the RAN gateway to multiple base stations looks like multicast, but the real time constraints are extremely tight. On the the reverse leg, however, traffic still needs to be combined in the wired network behind the base stations. In order to accommodate macrodiversity, the RAN would need to be a routing domain in which a multipath routing protocol that performed frame selection in the border routers and featured real time routing table convergence (for soft handoff) was in use. These characteristics involve a considerable change from existing IP routing algorithms (which do not require real time convergence and do not involve multipath nor selection of particular packets based on some algorithm).

While the prospects for moving IP into the RAN for transport of RAN protocols and data/voice traffic from the mobile are good, it seems unlikely that IP mobility will play any role in replacing CDMA soft handoff in the immediate future. The stratified RAN stack supporting CDMA soft handoff is a specialized, and therefore not a good candidate for replacement by more general network or application level mechanisms. In addition, even if IP is used for transport in the RAN, if voice over IP is to completely replace the current radio voice protocols, voice packets may need to be processed at the RAN gateway for maximum efficiency and robustness over the radio medium.

7.0 Summary

Most proposals for IP mobility require a one-to-one mapping between the mobile terminal and a base station with which it is in contact, and assume end-to-end connectivity and consequently routing in the radio access network based on the mobile's IP address. In CDMA networks, macrodiversity and the need for extremely low delay and jitter invalidate these assumptions. Consequently, IP mobility solutions are not applicable to CDMA soft handoff. These considerations do not, however, apply to hard handoff which occurs in the core network after frame selection.

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