Virtual Soft Hand-off in IP-Centric Wireless CDMA Networks

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Abstract

We present a novel method, *Virtual Soft Hand-off*, for wireless IP-centric CDMA networks whose routers, hosts and mobile stations have small group multicast (SGM) capability. The underlying ideas of the virtual soft hand-off method are that it

- views soft hand-off support as setting up an explicit *synchronous* multicast session among a small group of participants with dynamic group membership, and
- recovers multiple packet flows from the multiple received signals concurrently, and combines them to create a single packet flow at higher layers.

The virtual soft hand-off approach uses the Session Initiation Protocol (SIP) for setting up necessary multicast sessions.

1. Purpose and Scope

The growing demand for high-speed wireless access to the Internet is the driving force behind the current trend towards the design of IP-centric wireless networks comprising a large number of Pico-cells, each covered by an autonomous IP router base station. The CDMA spread spectrum communication technique seems to be more suitable for design of IP-centric wireless networks because it can achieve considerably higher capacity than other multiple access techniques. A key feature of CDMA that improves its capacity and performance is its soft hand-off capability that allows a mobile station to communicate with multiple base stations concurrently. However, accurate realization and use of soft hand-off in IP-centric wireless environments is too complex. This complexity has prompted some debate on not using the CDMA soft hand-off in IP-centric wireless networks [1]. Without any discussion on the merits of these suggestions, this paper presents a novel method, *virtual soft hand-off*, for IP-centric Wireless CDMA environments whose routers, hosts and mobile stations are SGM (small group multicast) capable [2] [3]. The underpinnings of virtual soft hand-off are that it

- views soft hand-off support as setting up an explicit *synchronous* multicast session among a small group of participants with dynamic group membership,
- recovers multiple IP packet flows from the multiple received signals,
- synchronizes contents of these packets using a delay equalization method, and
- combines them to synthesize a single packet flow for higher layers.

This paper is organized as follows: Section 2 provides an overview of the soft hand-off process and explains how current CDMA networks support it. In section 3, we describe the architecture of an IP-centric wireless CDMA network and highlight issues that hinder proper operation of current soft hand-off mechanisms in such an environment. Section 4 includes the description of proposed virtual soft hand-off mechanism. Finally, Section 5 concludes the paper with a summary of the scheme and a list of open issues

2. An Overview of Soft Hand-off

Figure 1 depicts the basic architecture of today's wireless CDMA networks, and illustrates the soft hand-off process schematically. Besides mobile stations/terminals, a wireless access network also comprises a radio access network (RAN), and an edge router and controller (ERC). Before delving into the soft hand-off process, let us briefly describe the elements of current wireless access networks as well as their basic functions.

- **Mobile Station (MS)**
  It is the user mobile terminal that allows users to communicate, and also provides means of interactions and control between users and the network.
- **Radio Access Network (RAN)**
  The radio access network (RAN) represents the wireless and back-haul infrastructure that provides MSs with wireless access to the wireline infrastructure. The coverage area of a RAN is partitioned into cells. A base station (BS) which is controlled by a base station controller (BSC) serves each cell. Thus, a RAN usually comprises a set of base stations (BSs) and base station controllers (BSCs), where
  - a ***Base Station (BS)*** is an adaptive remote radio multiplexer/demultiplexer that provides physical and link layer functions and essentially serves as a MAC layer repeater, and
  - a ***Base Station Controller (BSC)***[1] is a multi-port bridge (or switch) with an IP interface to ERC that interacts with the network control and management system (via the ERC) to control and manage base stations as well as their interaction with MSs. A BSC may control one or more BSs.
- **Edge Router & Controller (ERC)**
  An ERC is a routing and control system that connects a wireless access network to a regional wireline IP network. In practice, an ERC may support several RANs, though **Figure 1** shows only one. An ERC comprises two functional entities, an edge router (ER) and an edge control agent (ECA). The ER is an IP router, while the ECA is an intelligent agent that interacts with the control agent of the backbone IP network to control the RANs as well as support necessary network-wide control tasks. In the IP parlance, each ERC is the default gateway of all IP MSs that are supported by RANs that are connected to it. If economical, ERC and BSC may be implemented as a single physical entity.

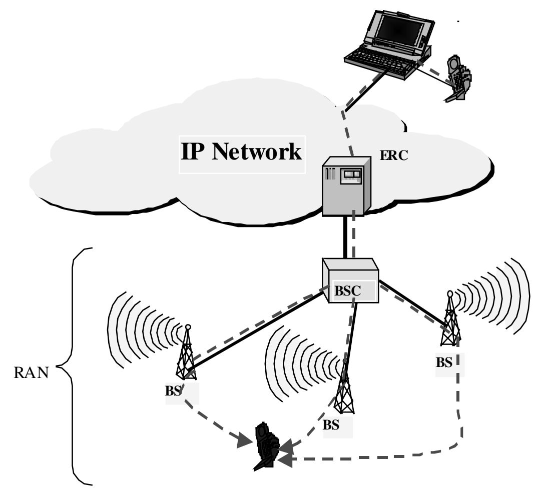

Figure 1. Soft hand-off in current wireless CDMA networks

Due to universal frequency reuse, wireless CDMA networks can utilize transmission to and reception from multiple adjacent BSs to support soft-hand-off for MSs (shown as dashed red lines in **Figure 1**). The soft hand-off process improves performance, reliability, and capacity of CDMA wireless networks [4]. Soft hand-off is a process whereby an MS can receive and send the same information simultaneously from and to different BSs. During soft-hand-off an MS commences communication with new BSs without interrupting communication with the old one, and receives or transmits multiple copies of the "same" signal from or to multiple BSs simultaneously. On the forward (*i.e.,* BS to MS) link, the MS combines[2] the received radio signals at the physical layer to improve the performance. On the reverse (*i.e.,* MS to BS) link, the most reliable BS usually prevail and its signal serves as the basis of estimation and detection of the received bits. The key requirement for supporting soft hand-off in a CDMA network is that:

[1] BSC is sometimes referred to as either the RAN gateway, wireless access gateway (WAG) or Radio network controller (RNC).

[2] The radio layer of the MS uses a weighted combination of the received radio signals as the basis of its hypothesis testing for estimation and detection of the received bits.

Multiple radio signals received from different BSs at the MS (or from the MS at different BSs) shall be synchronous, and shall contain identical user data.

In order to support soft hand–off and satisfy its stringent synchronization requirements, current CDMA RANs usually take the following measures.

1. A CDMA RAN provides means of stringent synchronization among its elements.
2. The BSC manages the transmission power of MSs and BSs to ensure low error rate as well as minimize the power consumption. Moreover, as the MS moves, the BSC interacts with it to select and maintain an "optimum" set of BSs with which the MS remains in contact.
3. On the forward link the BSC receives packets destined for the MS from the ERC, segments and assembles them into radio frames, and replicates the radio frames and transmits copies to BSs that are currently in contact with the MS.
4. On the reverse link, the BSC collects copies of the radio frames received from BSs that are currently in contact with the MS, selects one of them, and synthesizes IP packets for forwarding to the ERC.

In summary, in current wireless CDMA networks, the BSC is the focal anchoring point for synchronization, distribution and selection of frames and their contents during the soft hand-off.

3. IP-Centric Wireless CDMA Networks

Figure 2 depicts the architecture of an IP-centric wireless CDMA network, where a router base station that embodies functions of both BS and ERC serves each cell.

The key differentiating features of an IP-centric wireless CDMA network are that:

- Each cell is covered by a BS/ERC comprising the radio transceiver and ERC entities.
- Like other IP routers, BS/ERCs are autonomous and communicate via the IP wireline network.
- It runs network time protocol (NTP) across the end-to-end wireless/wireline IP platform to ensure strict end-to-end synchronization.

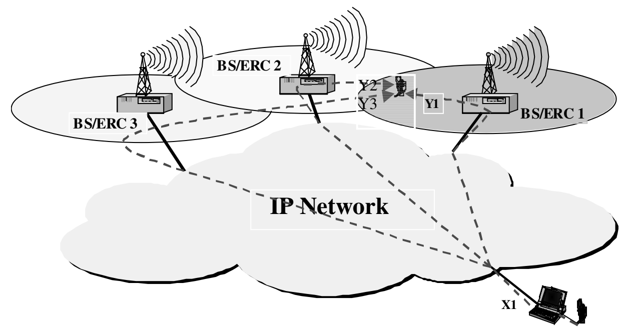

Figure 2. Architecture of a IP-centric wireless CDMA network

The red dashed lines of **Figure 2** illustrate the soft hand-off in an IP-centric wireless CDMA network, where the MS receives multiple packet flows simultaneously from multiple (*e.g.,* 3 in **Figure 2**) BS/ERCs that belong to different IP subnets. Today's CDMA networks use BSCs as the focal anchoring points for frame distribution and selection as well as content synchronization during soft hand-off. However, in an IP-centric environment, BS/ERCs are autonomous, and there is no focal anchoring point for control of soft hand-off. Thus, in an IP-centric CDMA environment, the soft hand-off process should be able to

i. *Provide means of efficient distribution of packet flows to multiple BS/ERCs*: Despite the absence of the BSC entity, packet flows should be efficiently distributed to multiple BS/ERCs?

ii. *Overcome loss of content synchronization*: Multiple packet flows destined for the MS experiences different loss and delay across the network, and lose their content synchronization.

iii. *Deal with the inaccuracy of signal combination at the radio layer:* Combination of radio signals at the physical layer of the MS results in erroneous synthesis of packets at higher layers because contents of their packet flows within received signals are not synchronized.

iv. *Allow the MS to select and maintain the active set of BS/ERCs:* In current CDMA systems the BSC selects and maintains the set of active BSs with which the MS in a contact. However, in an IP-centric CDMA environment the MS is better suited to do this task because there is no central control entity in such an environment.

We have developed the virtual soft hand-off method that resolves aforementioned issues in IP-centric CDMA environments.

3. The Virtual Soft Hand-off Process

This section focuses on the virtual hand-off, where we describe its foundations, its packet synthesis and distribution algorithm, and its operation on the forward and reverse links.

4. 1 Foundations of Virtual Soft Hand-off

The virtual soft hand-off is built upon two simple ideas and a basic requirement. Let us start with the ideas and then explain the requirement. First, it essentially views soft hand-off support as setting up an explicit *synchronous* multicast session among a small group of participants (*i.e.,* X1, Y1, Y2, and Y3 in **Figure 2**) with dynamic group membership. Second, unlike current soft hand-off schemes, it recovers multiple packet flows from the multiple received signals concurrently, and combines them to create a single packet flow for higher layers. The basic requirement for the realization of virtual soft hand-off is that routers, hosts, and MSs are SGM capable [2] [3]. This means that

i. A host and/or MS keeps track of destinations that it want to send packets to, and create packet headers that contain the list of destination addresses. We refer to these headers as SGM headers, hereafter.

ii. Each router is able to parse the SGM header, partitions destinations based on each destinations next hop, and forwards an appropriate SGM packet to the next hops (See [2] for further detail).

A CDMA system that supports virtual soft hand-off mechanism is able to perform the following basic functions.

- MSs and hosts time stamp each IP packet before forwarding it to the network to ensure strict synchronization among multiple received packet flows. Since this time stamp also serve as a sequence number within each flow[3], a forward error correction may be used to protect it against errors on the wireless media.
- When an MS detects a new pilot and determines that the signal strength is sufficient, the MS itself signals this new BS/ERC to commence communication with it[4]. Upon confirmation from the new BS/ERC, the MS updates its list of active BS/ERCs accordingly.
- As the MS commences communication with a new BS/ERC, it obtains a new IP address in the new subnet as well as keeps (or extends the lease of) its old IP address[5]. Note that in an IP-centric CDMA environment joining a new cell is the same as joining a new subnet. Each IP address identifies one of the fingers (shown as Y1, Y2, Y3 in **Figure 2**) of the CDMA Rake receiver which may have a SIP URL as well. For instance, if the Rake receiver of an MS has 3 fingers, they may be referred to as Y1 ≡ "user@host1", Y2 ≡ "user@host2", and Y3 ≡ "user@host3". This paradigm requires that a SIP user agent be able to support multiple URLs as well as IP addresses.

  Further study is needed to determine whether a SIP user agent (as defined in RFC 2543) is capable to support multiple URLs (and IP addresses), and what extensions are necessary (if any) to make it so.
- The MS periodically sends a "request message" to all BS/ERCs in its active list, and requests

[3] One may use RTP to provide this time-stamp for real-time applications or place the stamp in an extension header of IPv6.
[4] In current CDMA schemes, the MS signals its current BS, and the current BS serves as the intermediary between the MS and the new BS.
[5] In an IPv6 environment, an MS may use either DHCP or a Forward Address Assignment scheme for obtaining new addresses.

them to inform the MS about the strength of signals on its reverse links. The MS transmits its outbound packets to the BS/ERC whose reverse path signal strength is the highest[6].

- Whenever an MS decides to remove a BS/ERC from its active list, it releases the corresponding IP address, if necessary.
- The radio signals are not mixed at the physical layer (*i.e.,* the radio signal mixer of the CDMA receiver is disabled), and multiple packet flows are forwarded to the IP layer that will be mixed later (at IP ++ layer) to synthesize a single IP packet flow for higher layers.

  An end-to-end delay equalization method [5] is used for content synchronization. Each packet is forwarded to the higher layer mixer at time ($Ts + T$), where Ts is the time stamp within the packet, and T is an acceptable buffering delay within the MS. **Further study** is needed to determine how the value of threshold T should chosen.

Figure 3 illustrates the structure of a CDMA transceiver that supports virtual soft hand-off.

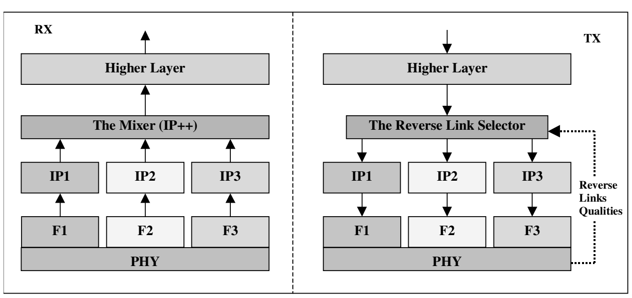

Figure 3. Schematic diagram of a CDMA transceiver with virtual soft hand-off

4.2 Packet Synthesis at IP++ Layer

In the virtual soft hand-off the IP layer forwards multiple packet flows up to the mixer at "IP++" layer. The mixer uses a simple majority rule to combine content of packets with identical time stamps and forwards a single packet to the higher layer. Suppose there are N soft hand-off legs and therefore N packets are forwarded to the mixer. The mixer reads each bit of these N packets concurrently. Suppose B_j, $1 \le j \le N$, and P_j, $1 \le j \le N$, represent the value of the bit in the *j-th* packet, the normalized strength of signal on the *j-th* leg, respectively. Then sets the bit to *1*, if $X = \sum_j P_j N_j > N/2$, and *0*, otherwise. However, when N is an even number and X = $N/2$, the mixer sets the value of the bit to the one received on the channel with strongest pilot. The complexity - performance trade-off of this packet synthesis mechanism as well as its comparison with current soft hand-off schemes, particularly with regard to the power requirements of BS/ERC require **further study.**

4.3 Operations of Virtual Soft Hand-off

For the sake of discussion, suppose that an MS and its corresponding host (CH) are already engaged in an ongoing SIP session when the MS enters the intersection of cells 1 and 2. At this point, it decides to initiate communication with first BS/ERC2 and then BS/ERC3. On the **forward link**, virtual soft hand-off operates as follows:

1. The MS detects the pilot of 2 is strong enough, it sends a request for communication to BS/ERC2. The BS/ERC2 accepts the request and responds with necessary radio parameters.
2. The MS requests for a new IP address from DHCP in subnet 2 (*i.e.,* cell 2) for Y2 as well as extends the lease of its current IP address in subnet 1 for Y1 ≡ "user@host1" .
3. The MS user agent sends a SIP REFER [6] message with Y2 ≡ "user@host2" in its Contact field to the CH user agent indicating that MS user agent wants CH user agent to invite Y2 ≡ "user@host2" to the session. In this scenario, the MS, the CH user agent, and Y2 ≡ "user@host2", play the roles of the "Transferor", the "Transferee", and the "Transfer Target", respectively. Note that this REFER request has no impact on the current ongoing session between Y1 ≡ "user@host1" and the CH, and leave it intact.
4. The CH user agent invites Y2 ≡ "user@host2" to the session by sending a SIP INVITE message. After the receipt of 200 OK from Y2 ≡ "user@host2", the CH SIP user agent sends

[6] For instance, current CDMA systems may have a command that allows the MS to request and get the strength of the reverse signals.

the ACK to Y2, and Y2 ≡ "user@host2" becomes part of the multicast session. Next, the CH SIP user agent send a NOTIFY message to the Y1 ≡ "user@host1" to inform it about the result of its REFER request.

5. The IP address of Y2 is added to the SGM destination list at the CH.
6. Similarly, Y3 ≡ "user@host3" joins this small multicast session, if necessary.
7. The multicast session is established and the data transfer continues on it.
   – The CH sends time-stamped packets with SGM headers to Y1, Y2, and Y3.
   – The MS receives multiple (*e.g.,* 3 in **Figure 2**), and forwards multiple packet flows to the IP layer so that it synthesizes a single packet flow for higher layer.

When a BS/ERC is removed from the active list and replaced with a new one, the associated finger gets a new IP address in the new subnet. Then, MS sends a REFER message to the CH indicating that the CH should invite the finger at its new address to join the session. The CH should also update its list of SGM destinations accordingly.

On the **reverse** link, the MS measures the signal strength of all BS/ERCs on the reverse link, and transmits packets to the one that has best signal quality. Of course, the source address in the outbound IP packets will be the same as that of the finger that transmits on the selected reverse link.

The algorithm for selection of the best reverse path by the MS may require additional mechanisms for signal measurement and interaction between the MS and BS/ERCs. These measurements and interactions require **further study**.

5. Summary and Open Issues

We have presented a novel method, *virtual soft hand-off*, for IP-centric Wireless CDMA environments whose routers, hosts and mobile stations are SGM capable. Unlike current soft hand-off schemes, the virtual soft hand-off

- views soft hand-off support as setting up an explicit *synchronous* multicast session among a small group of participants with dynamic group membership,
- recovers multiple IP packet flows from the multiple received signals,
- synchronizes contents of these packets using a delay equalization method, and
- combines them to synthesize a single packet flow for higher layers.

Among the open issues that needs further study are:

– the performance – complexity trade-off of the virtual soft hand-off process, and its comparison with current soft hand-off schemes,
– its impact on the current IETF signaling protocols such as session initiation protocol (SIP),
– the details of the reverse path selection algorithm.

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