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(54) RESOURCE UTILIZATION EFFICIENCY DURING HAND-OFF IN MOBILE COMMUNICATION SYSTEMS

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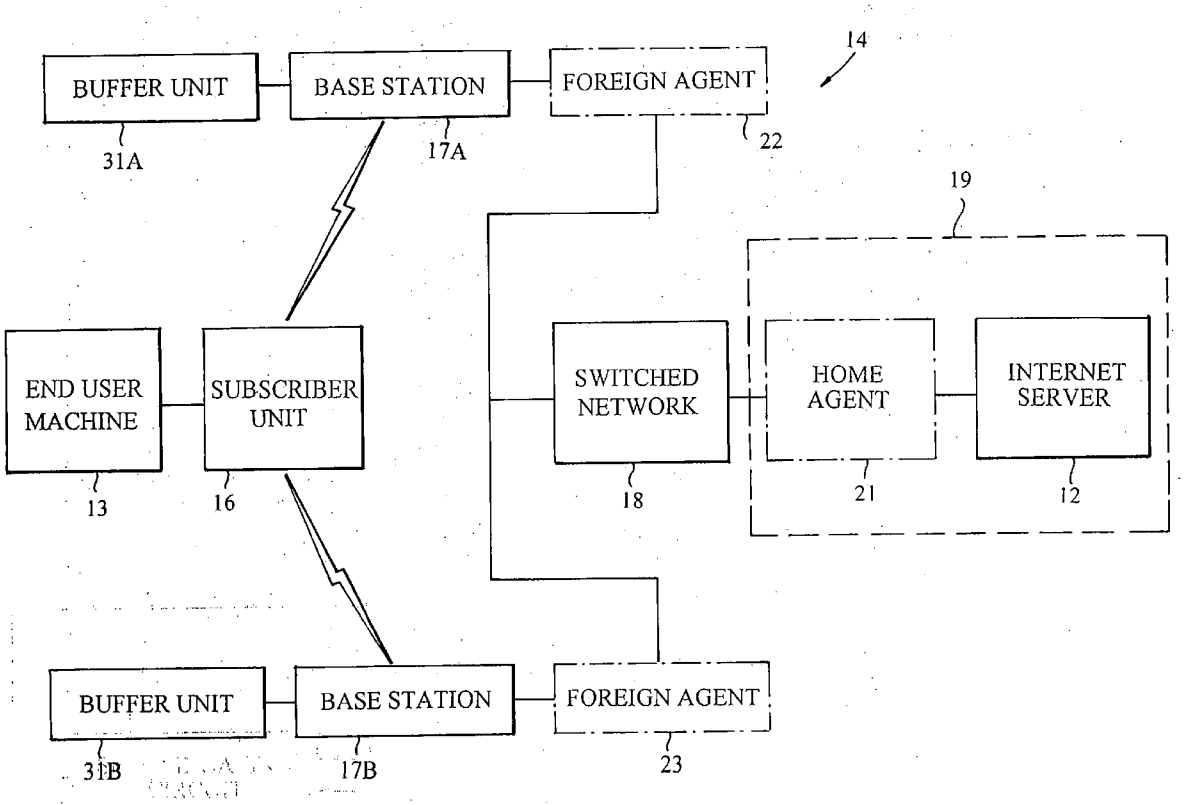
(57) **ABSTRACT**

An improved method of maintaining data throughput during handoff in a wireless communication link operating with the Mobile IP protocol is described. A first base station initially servicing a mobile subscriber unit is associated with a first Mobile IP foreign agent that is registered with the Mobile IP home agent as a first mobility binding between the subscriber unit and the home agent. When the subscriber unit issues a request to be handed off from the first base station to a second base station, a second foreign agent associated with the second base station is registered with the home agent as a simultaneous binding with the first mobility binding between the subscriber unit and the home agent. This permits both foreign agents to simultaneously receive a sequence of data packets from the home agent. Before handoff is executed, the data packet sequence routed to the second foreign agent is stored at the second base station. After handoff is complete, such stored packets are forwarded to the subscriber unit starting with a predetermined numbered packet in the stored sequence, and the first foreign agent is de-registered with the home agent.



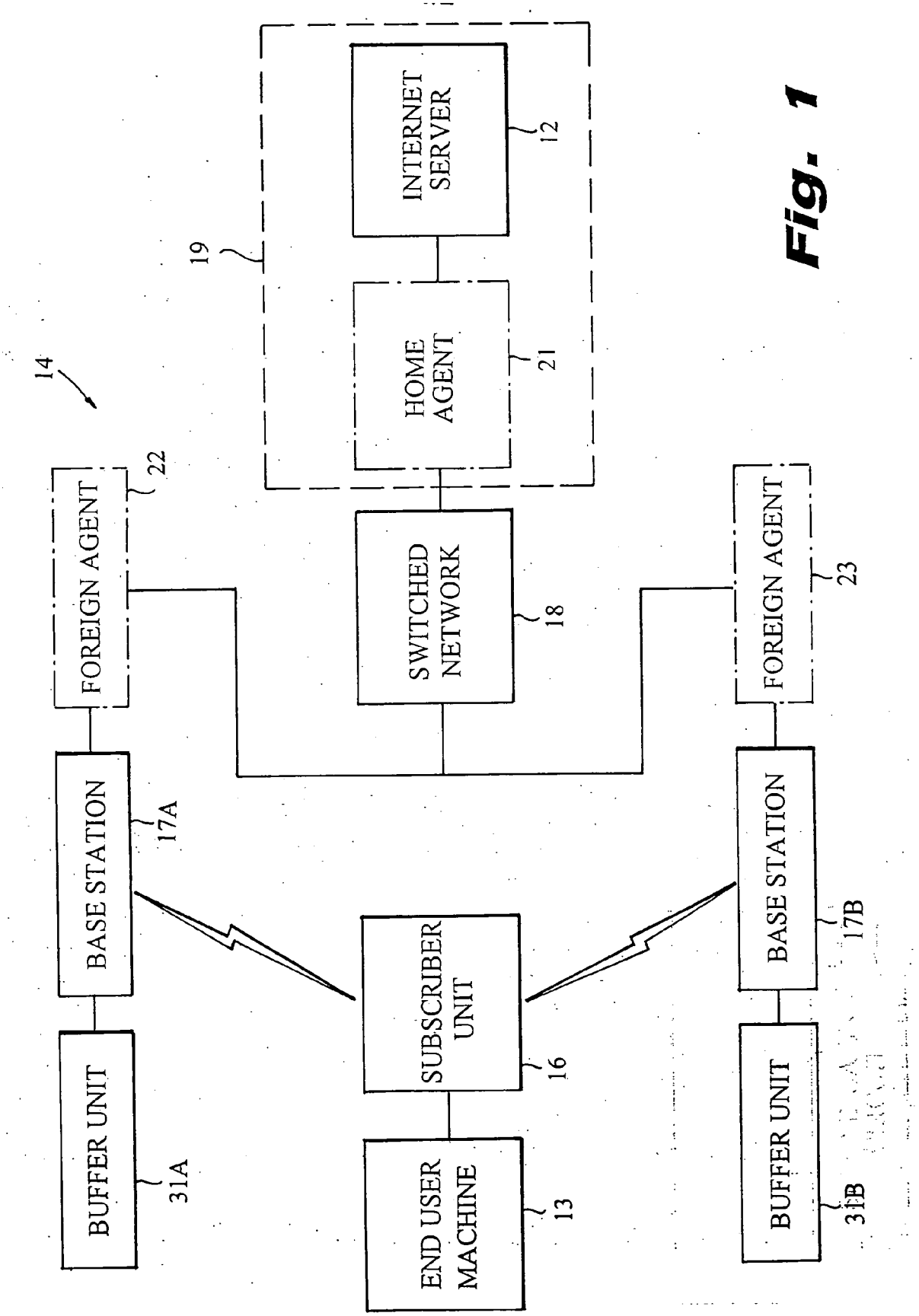

14
19
INTERNET SERVER
12
HOME AGENT
21
FOREIGN AGENT
22
SWITCHED NETWORK
18
FOREIGN AGENT
23
BASE STATION
17A
BASE STATION
17B
BUFFER UNIT
31A
SUBSCRIBER UNIT
16
BUFFER UNIT
31B
END USER MACHINE
13

Fig. 1

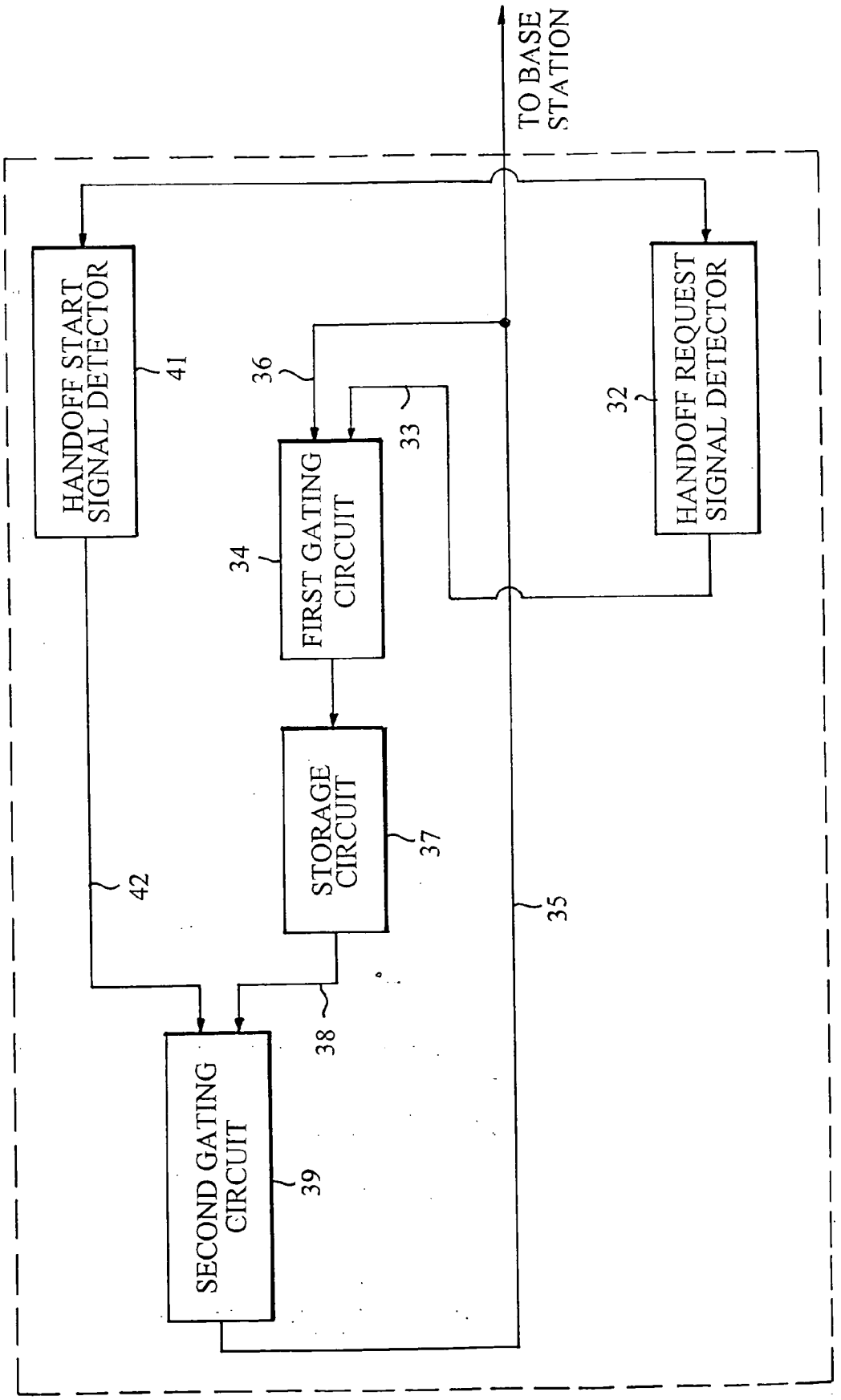

TO BASE STATION
HANDOFF START SIGNAL DETECTOR
41
HANDOFF REQUEST SIGNAL DETECTOR
32
36
33
34
FIRST GATING CIRCUIT
STORAGE CIRCUIT
37
42
35
38
SECOND GATING CIRCUIT
39
31B

Fig. 2

RESOURCE UTILIZATION EFFICIENCY DURING HAND-OFF IN MOBILE COMMUNICATION SYSTEMS

RELATED APPLICATION

[0001] This application is a continuation of application Ser. No. 09/802,128, filed on Mar. 8, 2001. The entire teachings of the above application are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] This invention relates to wireless communication systems, such as cellular packet networks, and more particularly to methods of and apparatus for improving efficiency in such systems during handoff.

[0003] In wireless communication systems for the transmission of data packets from a sending machine such as an Internet server, the switching or "handoff" of a mobile subscriber unit from one cellular base station to another is implemented as the subscriber unit moves between areas of different signal strength. Any discontinuities in the wireless data path as a result of a handoff can cause data packet loss, which results in missing or delayed acknowledgment signals between the end user machine and the server. This is true whether packets are destined for the end user machine or the server. This increases the likelihood that the applicable TCP protocols at either end of the network connection will invoke congestion avoidance/slow start modes at the server, leading to a drop in data throughput in the system.

[0004] In one arrangement for maximizing data throughput during periods of handoff, data packets destined for the subscriber unit are multicast to all of the base stations in the vicinity of the subscriber unit. Each of such base stations is identically tasked to store a succession of such data packets in an associated store-and-forward buffer or cache. When an actual handoff occurs from the base station then servicing the subscriber unit to a selected one of the other base stations with the identical cached packets, the selected base station forwards the stored packets in its own buffer to the subscriber unit. (In some cases, the use of additional "smart" facilities in the buffers to implement the so-called Snoop protocol can lead to further improvements in throughput).

[0005] While multicasting arrangements of this type can decrease the probability of lost packets to help maintain throughput in the system during handoff, they do not use the resources of the cellular system in an efficient way. All the base stations of the system that receive the multicast data packets from the server are tied up in the storage and processing of identical information for the same cellular customer, even though only one of such base stations will end up servicing such customer after handoff. The expensive facilities of all the other base stations in the group that are pressed into service in expectation of this particular handoff are unavailable for productive use elsewhere. In addition, by multicasting identical packets to so many different base stations, the load on the network infrastructure is unnecessarily increased.

SUMMARY OF THE INVENTION

[0006] The present invention preserves the advantage of store-and-forward buffer systems in maintaining data throughput during a handoff while avoiding the disadvantages resulting from multicasting data packets to all of the base stations of the system. Rather than multicasting to all base stations within the vicinity of the subscriber, the invention makes use of the simultaneous bindings capability of the Mobile IP protocol to simultaneously send packets to only the two base stations involved in the handoff.

[0007] Illustratively, when the subscriber unit issues a request for handoff from a current first base station to a new second base station, the system is reconfigured (e.g., through a simultaneous binding registration process) so that data packets then being transmitted by the server to the first base station are also sent to the second base station and stored in the latter's buffer. None of the other base stations on the system are designated to receive such copies, so such other base stations remain fully available for use with other customers.

[0008] In one implementation of the handoff execution process, the subscriber unit notifies the second base station to start forwarding, to the subscriber unit, the sequence of stored data packets in its buffer, starting with a specified sequence number. When such forwarding starts, the subscriber unit also notifies the original base station to stop transmitting data packets to the subscriber (e.g. by de-registering the Mobile IP binding with the original base station). In this way all the base stations of the system except for the new second base station are made available for use elsewhere.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The invention is further illustrated in the following detailed description taken in conjunction with the appended drawing, in which:

[0010] **FIG. 1** is a block diagram of a wireless communication system which uses the Mobile IP protocol and which is configured to implement the algorithm of the invention; and

[0011] **FIG. 2** is a representation of a base station store-and forward buffer used in connection with the system of **FIG. 1**.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Referring to **FIG. 1**, there is depicted a wireless communication system **11**, such as a cellular packet network, which illustratively operates according to the Mobile IP protocol. The system **11** is adapted for the two-way transmission of digital data packets between an Internet server **12** and an end user machine **13**. The end user machine **13** may be a laptop computer, a portable computer, a personal digital assistant (PDA), or the like, which may be moved from place to place.

[0013] The system **11** has a wireless link **14** that includes a mobile subscriber unit **16** and a multiplicity of base stations **17**, two of which (identified as **17**A and **17**B) are illustrated. The subscriber unit **16** is coupled to the end user machine **13**. The base stations **17**A and **17**B are connected to the server **12** through a switched network **18**, illustratively the Internet. Data packets transmitted from the server **12** to the end user machine **13** are routed through the switched network **18**, a selected one of the base stations **17**A and **17**B,

and the subscriber unit **16**. For purposes of this description, it will be assumed that in an initial condition of the wireless link **14**, the subscriber unit **16** is serviced by the base station **17**A.

[**0014**] Handoff of the subscriber unit **16** from base station **17**A to base station **17**B as the subscriber unit **16** moves within range of the base station **17**B is implemented in a normal manner in accordance with the relative strength of beacon or pilot signals transmitted to the subscriber unit from the base stations. In particular, if the signal strength from the base station **17**B as measured at the subscriber unit **16** becomes sufficiently greater than that of the base station **17**A, the subscriber unit **16** will request a handoff from the base station **17**A to the base station **17**B.

[**0015**] In the system **11** as illustrated, the subscriber unit **16** also forms the mobile node of a Mobile IP home network **19**, which may be an Internet service provider. The subscriber unit **16** is assigned a Mobile IP address by a home agent **21** of the home network **19**. Home agent **21** intercepts data packets that are transmitted by the server **12** and bear the subscriber unit's Mobile IP address. After encapsulating the data packets from the server **12** into Mobile IP packets in accordance with Mobile IP protocols, the home agent **21** routes them to a foreign agent **22** that is associated with the base station **17**A and is registered with the home agent **21** as a "binding" for the subscriber unit **16**. The foreign agent **22** unencapsulates the Mobile IP packets and sends them on to the subscriber unit **16** through the base station **17**A.

[**0016**] In the event of a hand-off of the subscriber unit **16** from base station **17**A to base station **17**B, the home agent will thereafter route the Mobile IP-encapsulated data packets bearing the subscriber unit's Mobile IP address to a different foreign agent **23** that is registered with the home agent **21**. The foreign agent **23** is associated with the base station **17**B and is registered with the home agent **21** as another "binding" for the subscriber unit **16**. The foreign agent **23** unencapsulates the intercepted Mobile IP data packets which are currently transmitted by the home agent **21** before sending them on to the subscriber unit **16** through the base station **17**B.

[**0017**] The base stations **17**A and **17**B are further associated with buffer units **31**A and **31**B, respectively, which operate in a store and forward mode to maintain data throughput in system **11** during periods of handoff. Store and forward buffer systems have been used with some success in the prior art as part of systems designed to maintain handoff efficiency in wireless links. As indicated before, however, such known arrangements are wasteful and inefficient in their use of system resources. In such arrangements, which may also operate with Mobile IP protocols, the base stations in the vicinity of the subscriber unit are organized by their home network into an IP multicast group for the simultaneous receipt from the home agent of data packets destined for the mobile node. Such mobile node, in turn, is assigned a temporary multicast IP address. With these arrangements, all the base stations in the IP multicast group are forced to expend their resources in storing and processing identical received data packets in their buffers even though only one of such base stations can be selected to actually forward such packets to the mobile node in the event of a particular handoff.

[**0018**] In accordance with the invention, the Mobile IP-based system depicted in **FIG. 1** is operated in a way that both preserves the advantage of store and forward buffering during handoff and uses the resources on the network very efficiently. As in previous arrangements, data packets from the server **12** which are destined for the subscriber unit **16** are intercepted by the home agent **21**. However, instead of being multicast to all the base stations in the vicinity of the subscriber unit **16**, they are initially routed, via the already registered foreign agent **22**, only to the base station **17**A that is then servicing the customer. After the foreign agent **22** removes the Mobile IP headers from the packets, the base station **17**A routes them to the subscriber unit **16**. No other base stations associated with the system **11** are utilized during this process, and their resources are available for other tasks.

[**0019**] When a handoff is to occur from base station **17**A to base station **17**B, the subscriber unit **16** sends a handoff request to the new base station **17**B. The handoff request from the subscriber unit includes a Mobile IP Registration Request, notifying the home agent **21** of its new point of attachment via foreign agent **23**. However, in accordance with the invention, the latter request is for so-called simultaneous binding; that is, the subscriber unit **16** requests a designation for simultaneous receipt, along with the already registered foreign agent **22**, of data packets from the home agent **21**.

[**0020**] The home agent **21** acknowledges such request for simultaneous binding by sending a Mobile IP registration Reply back to the subscriber unit **16** via the foreign agent **23**. When such set-up is complete, any data packets coming from the server **12** and addressed to the subscriber unit **16** will be simultaneously routed to both the base station **17**A and the base station **17**B. The buffer unit **31**B associated with the base station **17**B stores the sequence of packets routed to the foreign agent **23** from the home agent **21**. These packets are cached at the buffer unit **31**B and are not yet forwarded to the subscriber unit **16**.

[**0021**] To commence the execution of handoff, the subscriber unit **16** generates a handoff start signal which is applied to the base stations **17**A and **17**B. This functions to direct buffer unit **31**B to commence forwarding the data packets stored therein to the subscriber unit **16** starting with a predetermined sequence number of the stored packets. It also functions to direct buffer unit **31**A to cease sending data packets to the subscriber unit **16** at that time, and to continue caching them. Thereafter, the subscriber unit **16** sends a handoff complete signal to the base stations **17**A and **17**B. The handoff signal to the base station **17**A includes a Mobile IP registration request with a lifetime value equal to zero, notifying the home agent **21** that the mobility binding to the subscriber unit **16** via the foreign agent **22** is no longer valid. In reply, the home agent **21** sends an acknowledgement back to the subscriber unit **16**. As a result, the base station **17**A will no longer receive data packets from the home agent **21**, freeing up the base station resources for other tasks. The handoff complete signal sent to the base station **17**B indicates that the handoff process has been completed.

[**0022**] **FIG. 2** shows an illustrative embodiment of the buffer unit **31**B associated with the base station **17**B for implementing several of the steps of the inventive process. The handoff start signal generated by the subscriber unit after set-up of the Mobile IP simultaneous binding is detected by a detector **32**, and the output of the detector **32**

is applied to a control input **33** of a first gating circuit **34**. The numbered sequence of data packets now being transmitted to the base station **17**B from the home agent **21** (**FIG. 1**) via the foreign agent **23** is applied over a common data line **35** (**FIG. 2**) to a second input **36** of the gating circuit **34**. The output of the gating circuit **34** is applied to a storage circuit **37**, which is implemented to output an externally selectable subset(s) of the data packet sequence stored in the circuit **37**. The output of the storage circuit **37** is applied to a main input **38** of a second gating circuit **39**.

[**0023**] The handoff start signal generated by the subscriber unit is detected by a detector **41**. The output of detector **41** is applied to a control input **42** of the gating circuit **39** and serves to gate, to the common data line **35**, a subset of the packets stored in the storage circuit **37** starting with the sequence number specified by the handoff start signal. The resulting succession of outputted packets are coupled via the base station **17**B (**FIG. 1**) to the subscriber unit **16**.

[**0024**] It will be understood that the buffer unit **31**A associated with the base station **17**A can be implemented in a manner similar to that of buffer unit **31**B for carrying out corresponding store and forward functions.

[**0025**] In the foregoing, the invention has been described in connection with an illustrative implementation thereof. Many variations and modifications will now occur to those skilled in the art. For example, it will be appreciated that implementing the steps of the invention before, during and after handoff execution may employ various modes of communication, simultaneous or otherwise, between the subscriber unit and the respective base stations involved in the handoff and/or between the base stations themselves. It is accordingly desired that the scope of the appended claims not be limited to the specific disclosure herein contained.

1-10. (canceled)

11. A method for improving resource utilization efficiency during handoff in a communication system, the method comprising:

establishing a binding between a first base station and a subscriber unit, the binding causing data destined for the subscriber unit that is transferred from a home agent to the first base station to be cached at the first base station;

establishing a binding between a second base station and the subscriber unit, the binding causing data destined for the subscriber unit that is transferred from the home agent to the second base station to be cached at the second base station; and

generating a registration request configured to cause the home agent to forward data received by the home agent and destined for the subscriber unit to both the first base station and the second base station.

12. A method as defined in claim 11 further comprising:

forwarding the registration request to the home agent.

13. A method as defined in claim 12 further comprising:

receiving an acknowledgment from the home agent wherein the acknowledgment acknowledges the registration request.

14. A method as defined in claim 11 wherein the registration request is a Mobile Internet Protocol (IP) registration request.

15. A method as defined in claim 11 further comprising:

generating a handoff start signal configured to cause the first base station to end forwarding data contained in its cache that is destined for the subscriber unit to the subscriber unit; and

forwarding the handoff start signal to the first base station.

16. A method as defined in claim 11 further comprising:

generating a handoff start signal configured to cause the second base station to begin forwarding data contained in its cache that is destined for the subscriber unit to the subscriber unit; and

forwarding the handoff start signal to the second base station.

17. A method as defined in claim 11 further comprising:

generating a second registration request configured to notify the home agent to no longer bind the subscriber unit with the first base station.

18. A method as defined in claim 17 further comprising:

forwarding the second registration request to the home agent.

19. A method as defined in claim 17 wherein the second registration request is a Mobile IP registration request.

20. An apparatus for improving resource utilization efficiency during handoff in a communication system, the method comprising:

means for establishing a binding between a first base station and a subscriber unit, the binding causing data destined for the subscriber unit that is transferred from a home agent to the first base station to be cached at the first base station;

means for establishing a binding between a second base station and the subscriber unit, the binding causing data destined for the subscriber unit that is transferred from the home agent to the second base station to be cached at the second base station; and

means for generating a registration request configured to cause the home agent to forward data received by the home agent and destined for the subscriber unit to both the first base station and the second base station.

21. An apparatus as defined in claim 20 further comprising:

means for forwarding the registration request to the home agent.

22. An apparatus as defined in claim 21 further comprising:

means for receiving an acknowledgment from the home agent wherein the acknowledgment acknowledges the registration request.

23. An apparatus as defined in claim 20 wherein the registration request is a Mobile Internet Protocol (IP) registration request.

24. An apparatus as defined in claim 20 further comprising:

means for generating a handoff start signal configured to cause the first base station to end forwarding data contained in its cache that is destined for the subscriber unit to the subscriber unit; and

means for forwarding the handoff start signal to the first base station.

25. An apparatus as defined in claim 20 further comprising:

means for generating a handoff start signal configured to cause the second base station to begin forwarding data contained in its cache that is destined for the subscriber unit to the subscriber unit; and

means for forwarding the handoff start signal to the second base station.

26. An apparatus as defined in claim 20 further comprising:

means for generating a second registration request configured to notify the home agent to no longer bind the subscriber unit with the first base station.

27. An apparatus as defined in claim 26 further comprising:

means for forwarding the second registration request to the home agent.

28. An apparatus as defined in claim 26 wherein the second registration request is a Mobile IP registration request.

29. A method for improving resource utilization efficiency during handoff in a communication system, the method comprising:

establishing a binding between a first base station and a subscriber unit, the binding causing data destined for the subscriber unit that is transferred from a home agent to the first base station to be cached at the first base station;

establishing a binding between a second base station and the subscriber unit, the binding causing data destined for the subscriber unit that is transferred from the home agent to the second base station to be cached at the second base station; and

receiving a request to forward data received by the home agent and destined for the subscriber unit to both the first base station and the second base station.

30. A method as defined in claim 29 further comprising:

forwarding data received by the home agent to both the first base station and the second base station.

31. A method as defined in claim 29 wherein the request is a Mobile Internet Protocol (IP) registration request.

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