US006208627B1

(12) **United States Patent**
Menon et al.

(10) **Patent No.: US 6,208,627 B1**
(45) **Date of Patent: Mar. 27, 2001**

(54) **SIGNALING AND PROTOCOL FOR COMMUNICATION SYSTEM WITH WIRELESS TRUNK**

(75) Inventors: **Narayan P. Menon**, Colorado Springs; **Konrad G. R. Roeder**, Woodland Park, both of CO (US)

(73) Assignee: **Xircom, Inc.**, Thousand Oaks, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/988,546**

(22) Filed: **Dec. 10, 1997**

(51) **Int. Cl.**[7] **H04Q 7/00**
(52) **U.S. Cl.** **370/328**; 370/360
(58) **Field of Search** 370/328, 360, 370/469; 455/424, 404, 469

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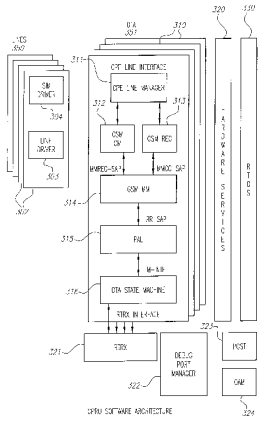
(57) **ABSTRACT**

A communication system having a wireless trunk for connecting multiple phone lines over wireless communication links to a cellular network comprises a central telephone switch, such as a private branch exchange or key system, connected through one or more trunk lines to a wireless access communication unit. The wireless access communication unit preferably comprises a separate subscriber interface for each trunk line from the central telephone switch. The wireless access communication unit collects data from each of the subscriber interfaces, formats the data into a format compatible with an over-the-air protocol, and transmits the information over one or more wireless channels to a cellular base station. The wireless access communication unit thereby connects calls received from the central telephone switch's trunk lines over a wireless trunk to a network. A controller within the wireless access communication unit interfaces the subscriber interfaces with a radio transceiver, and assists in the conversion of data from a format suitable for wireless transmission. The controller also assists in distributing data received over the wireless trunk to the separate subscriber interfaces, and converting the data to a format suitable for communication with the central telephone switch. Calls may be selectively routed by the central telephone switch over landlines, instead, to the wireless access communication unit, thereby bypassing landlines.

31 Claims, 26 Drawing Sheets



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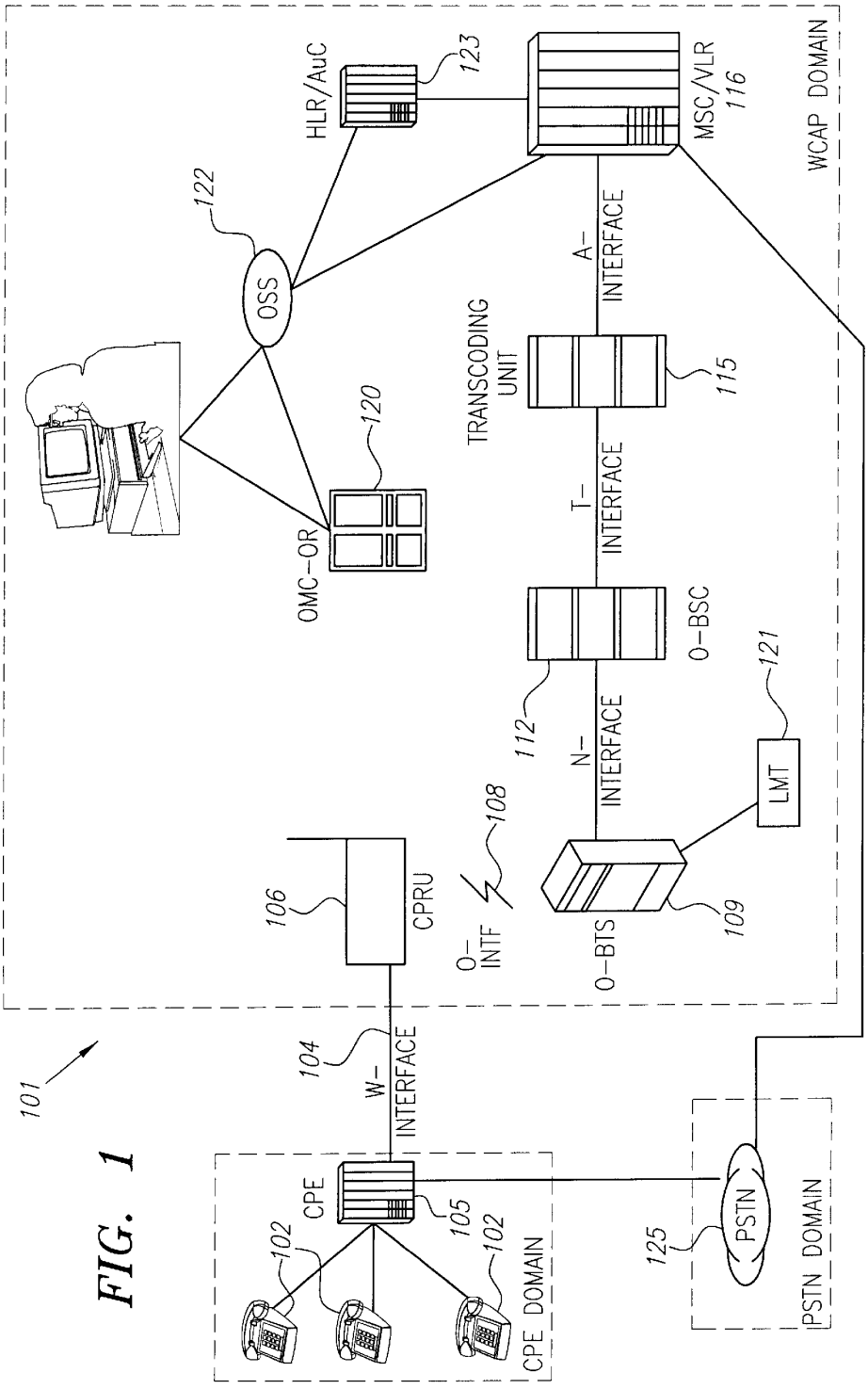

FIG. 1

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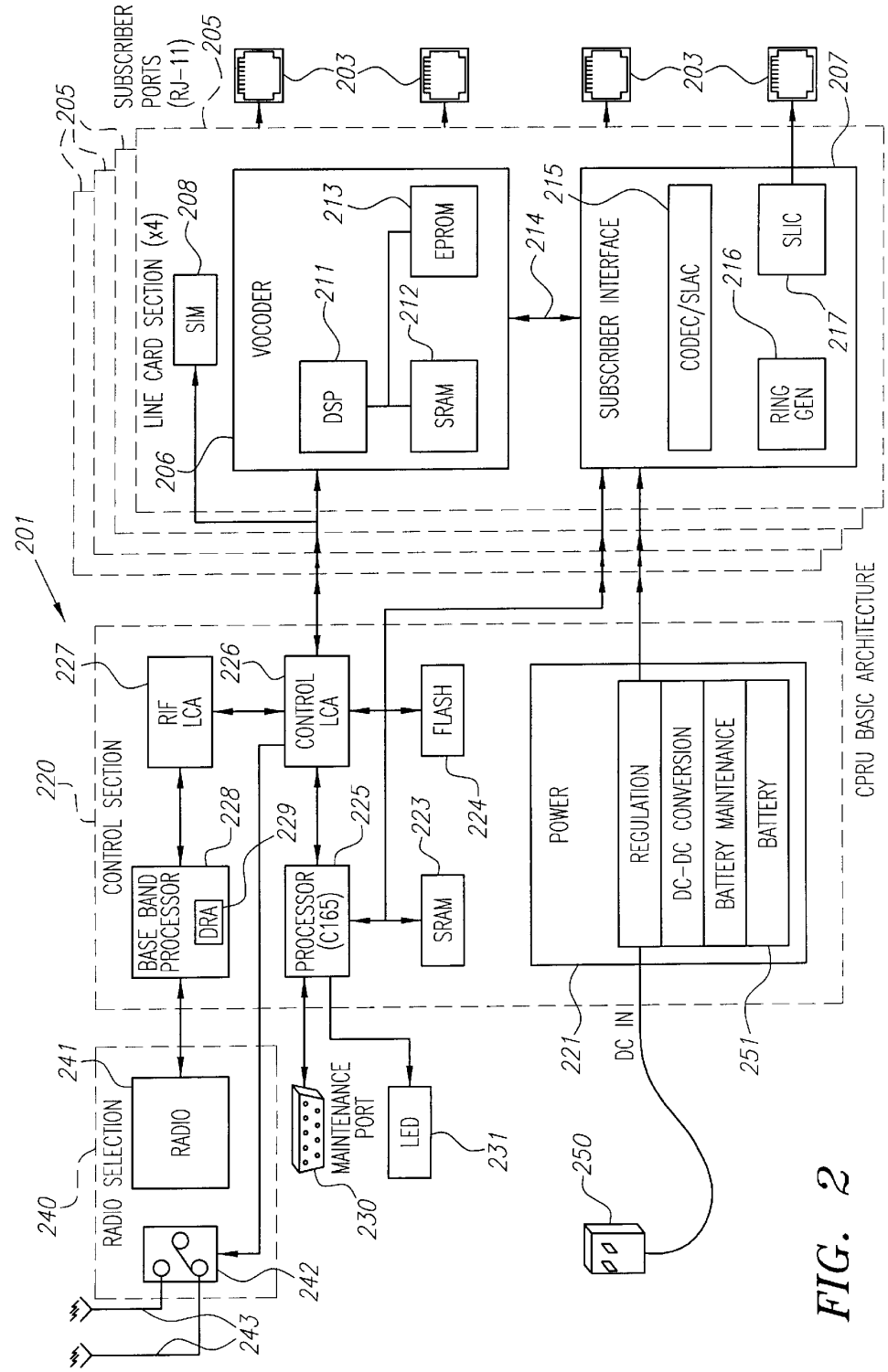

FIG. 2

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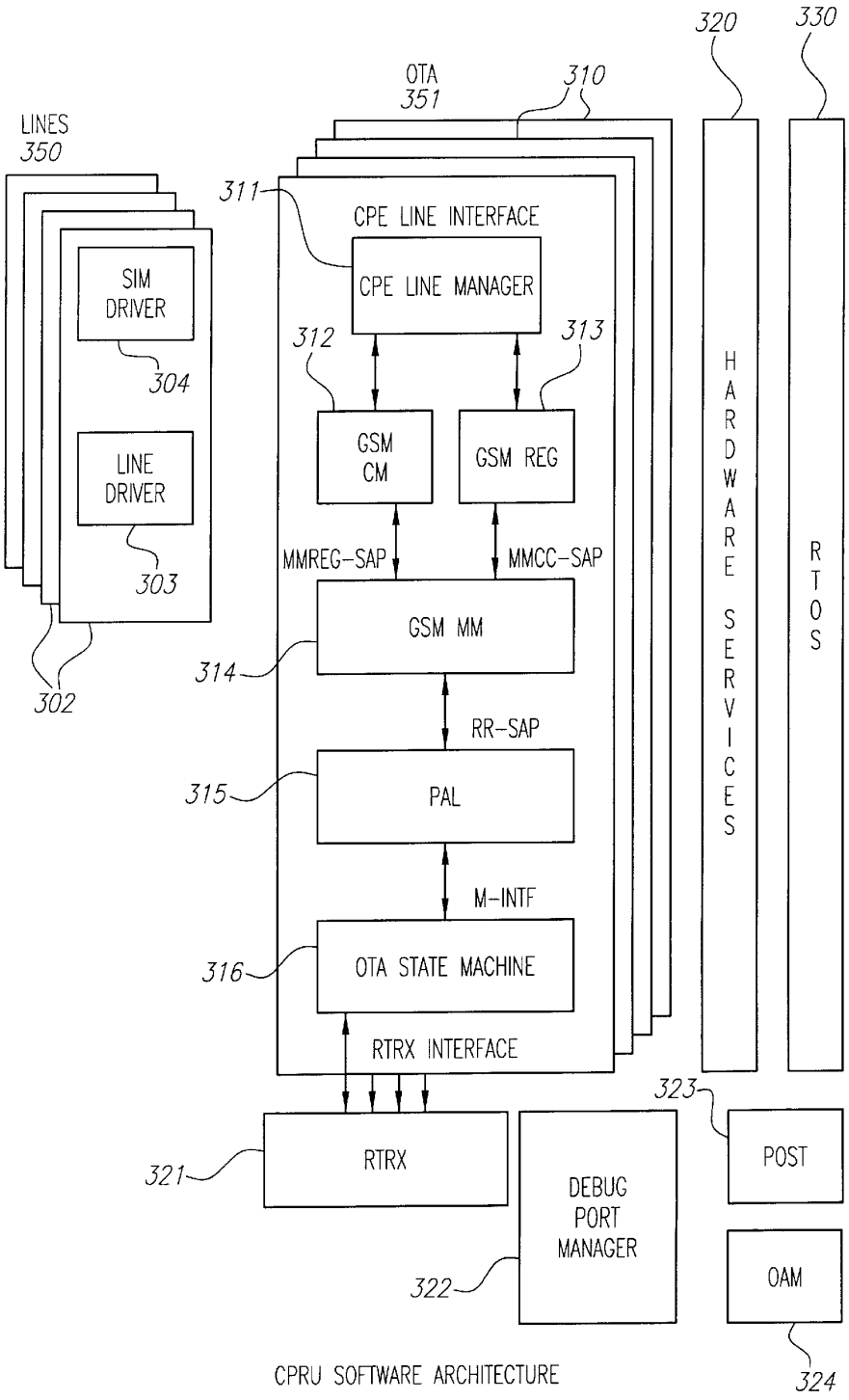

FIG. 3

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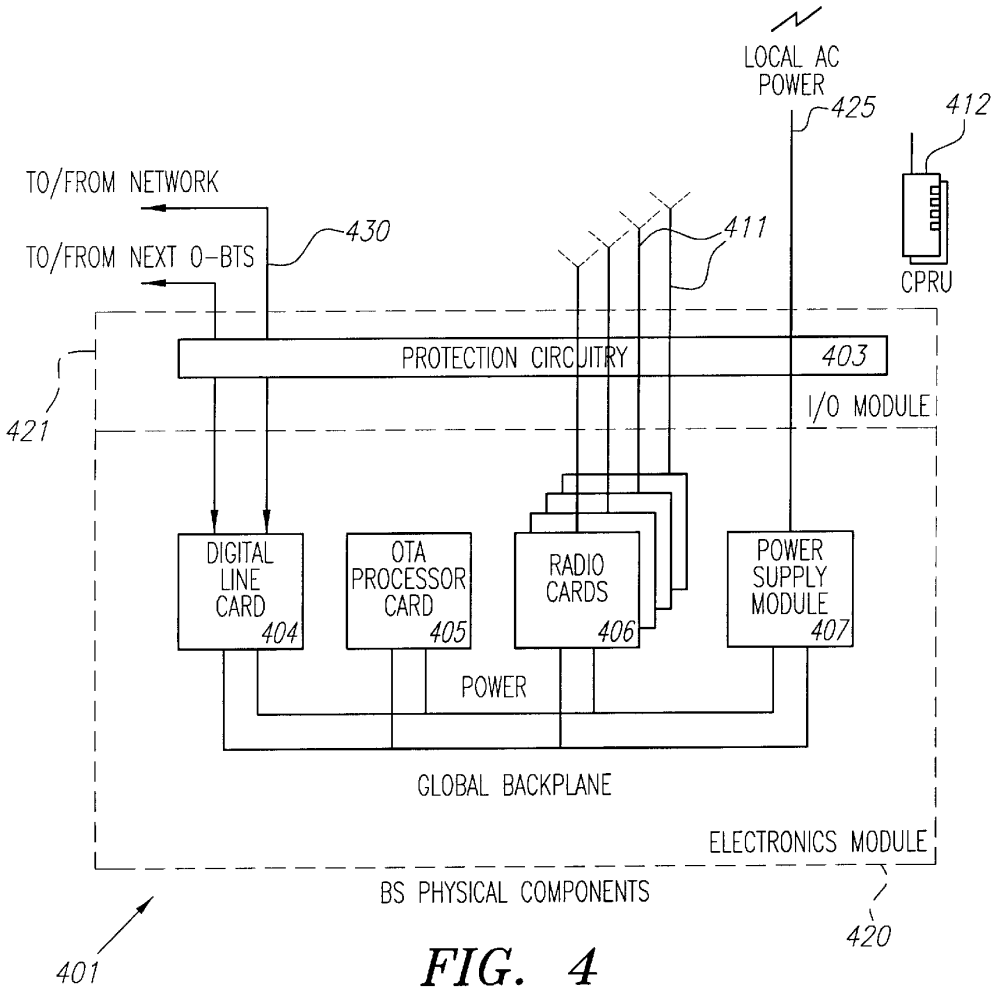

FIG. 4

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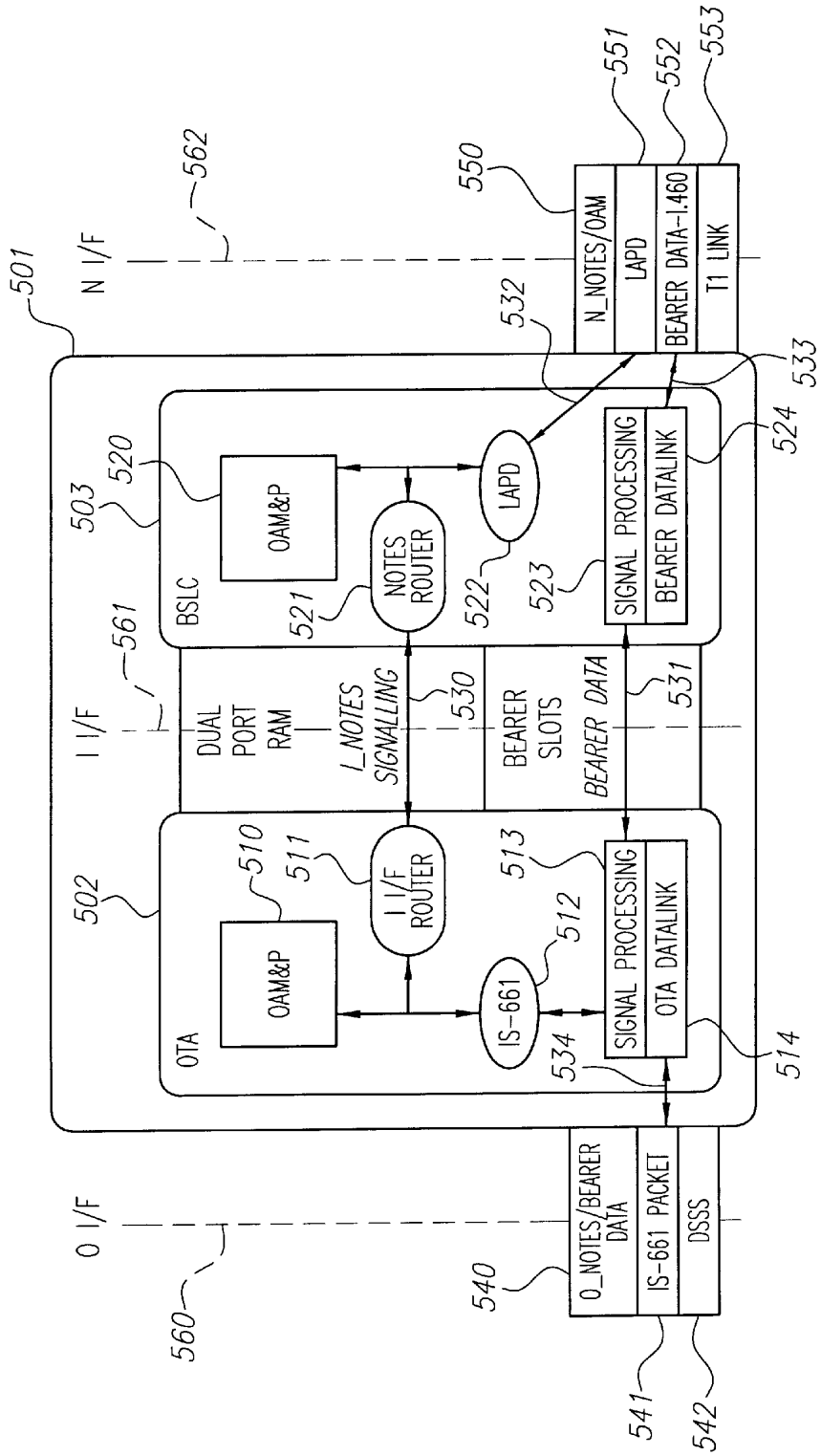

BS HIGH LEVEL SOFTWARE ARCHITECTURE

FIG. 5

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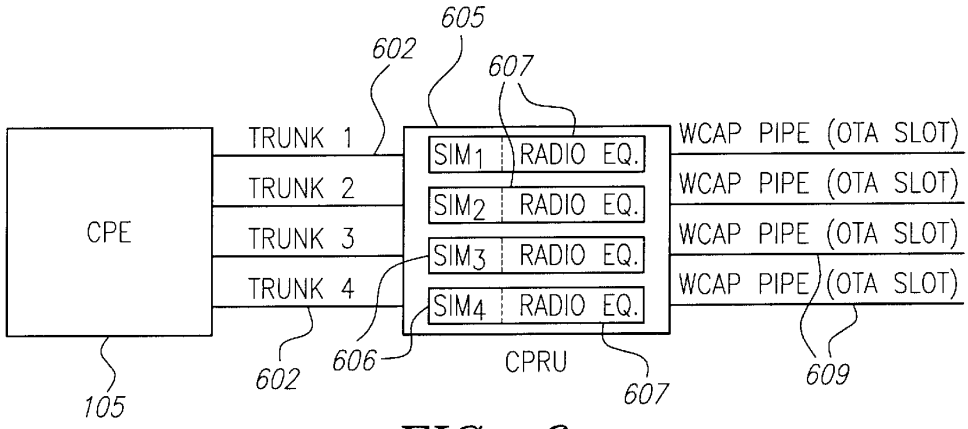
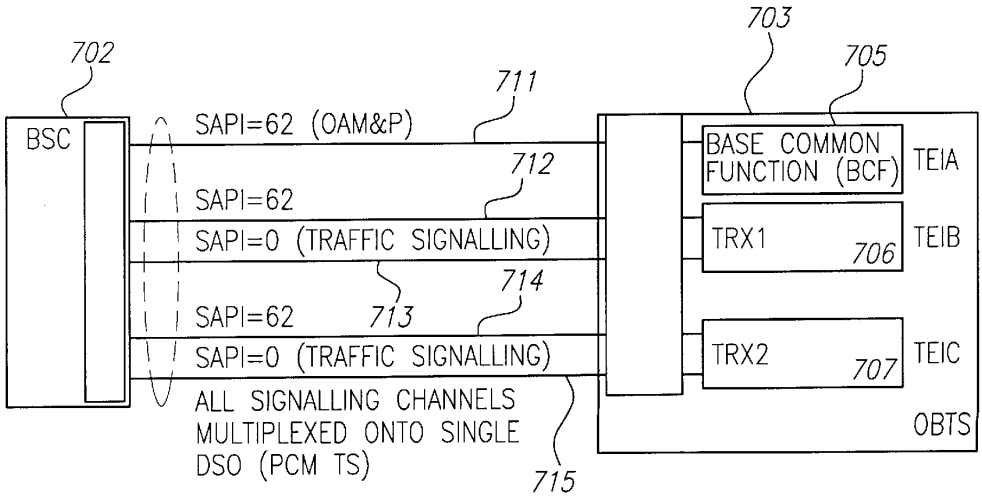


FIG. 6



INTERFACE SIGNALLING STRUCTURES

FIG. 7

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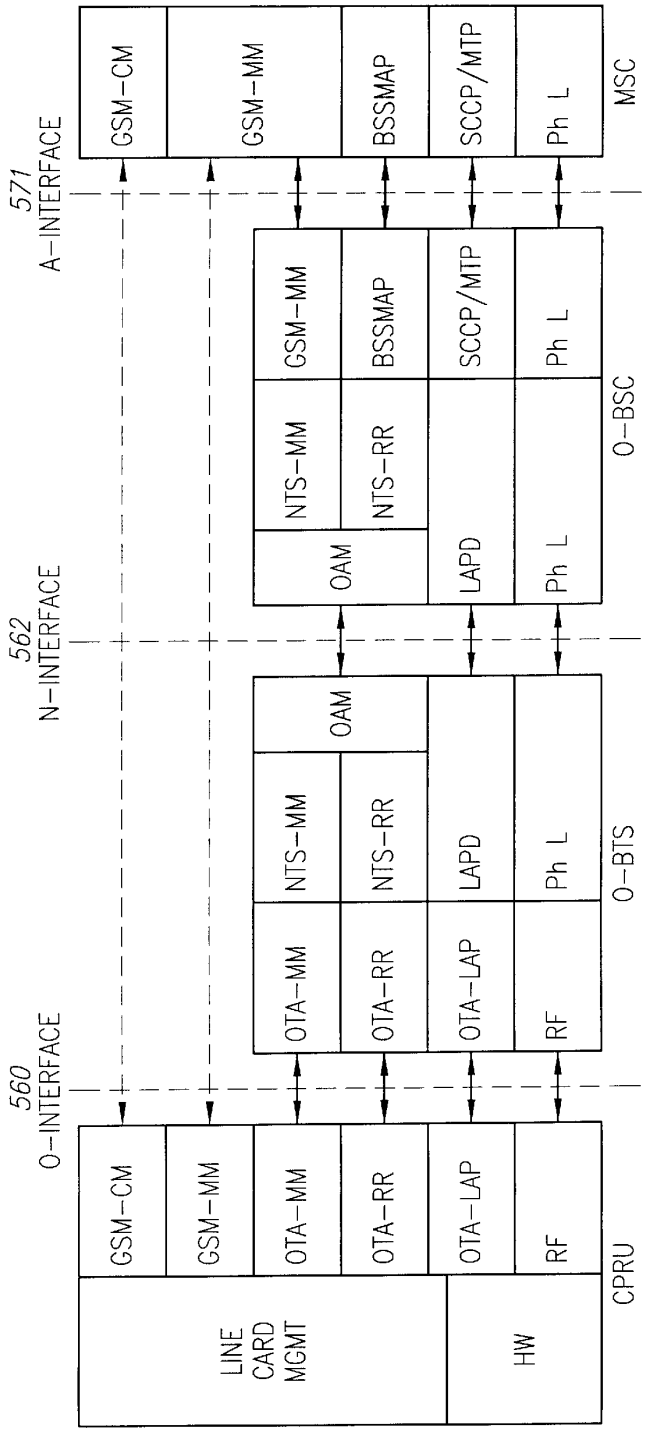

FIG. 8

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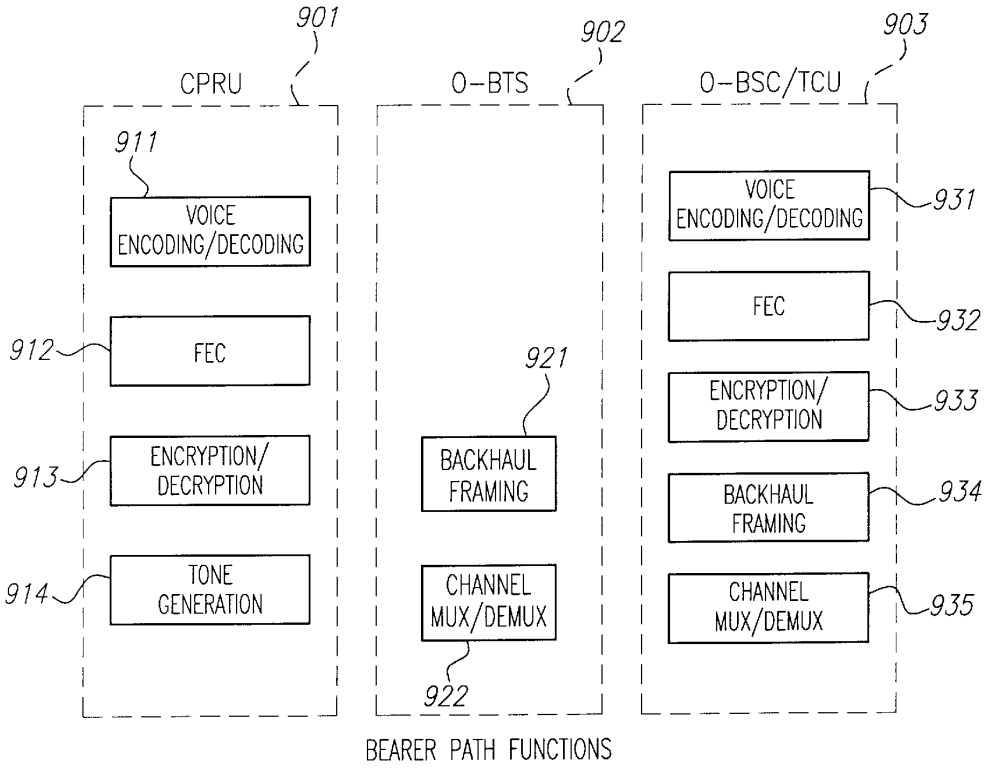

FIG. 9

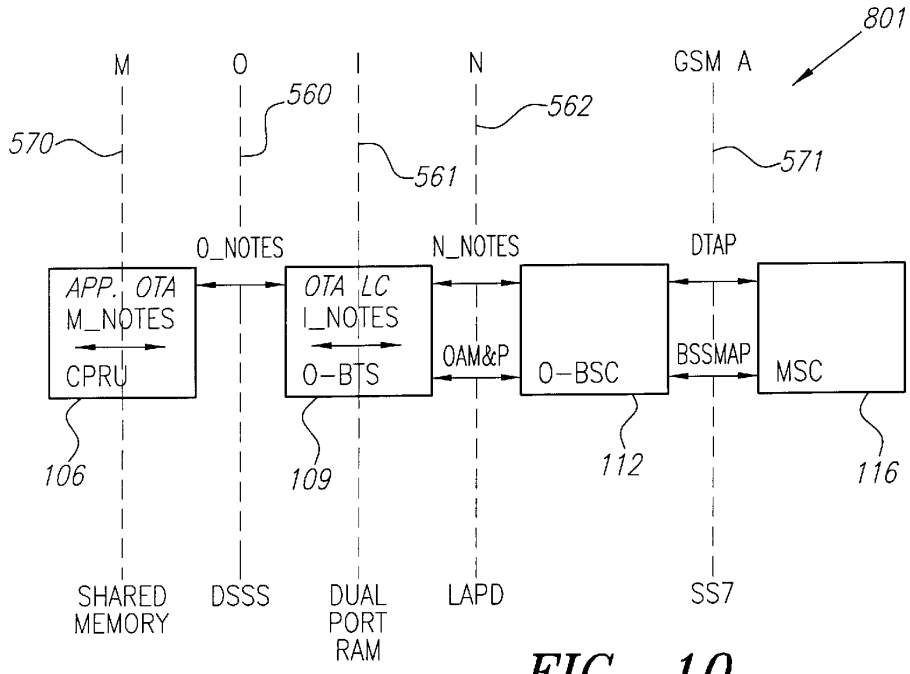

FIG. 10

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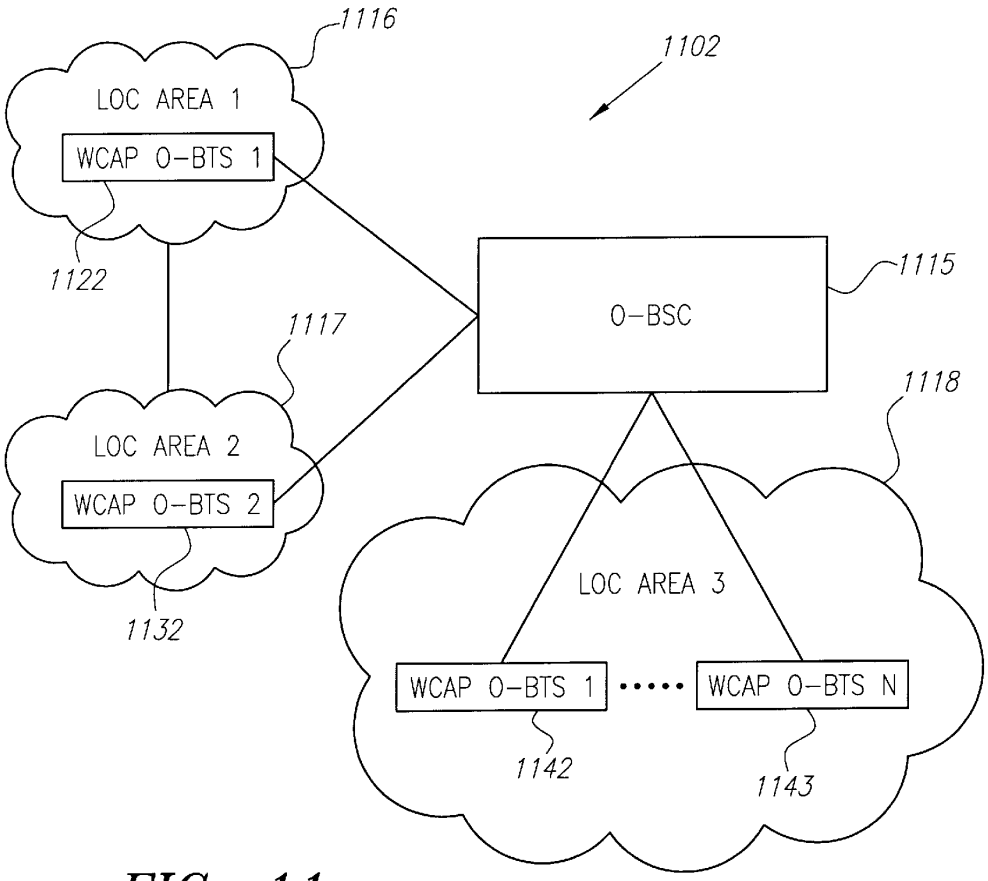

FIG. 11

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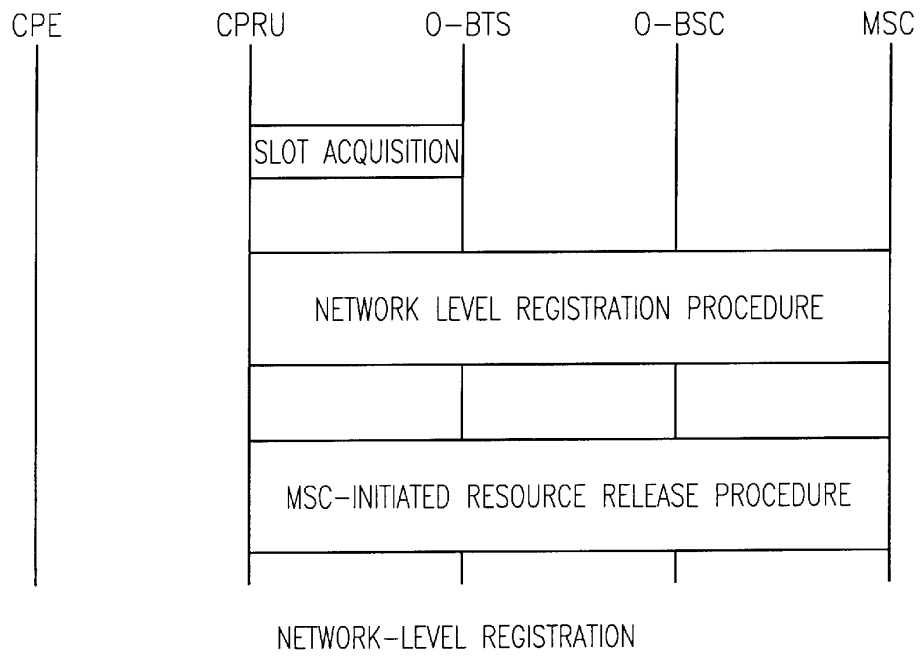

FIG. 12

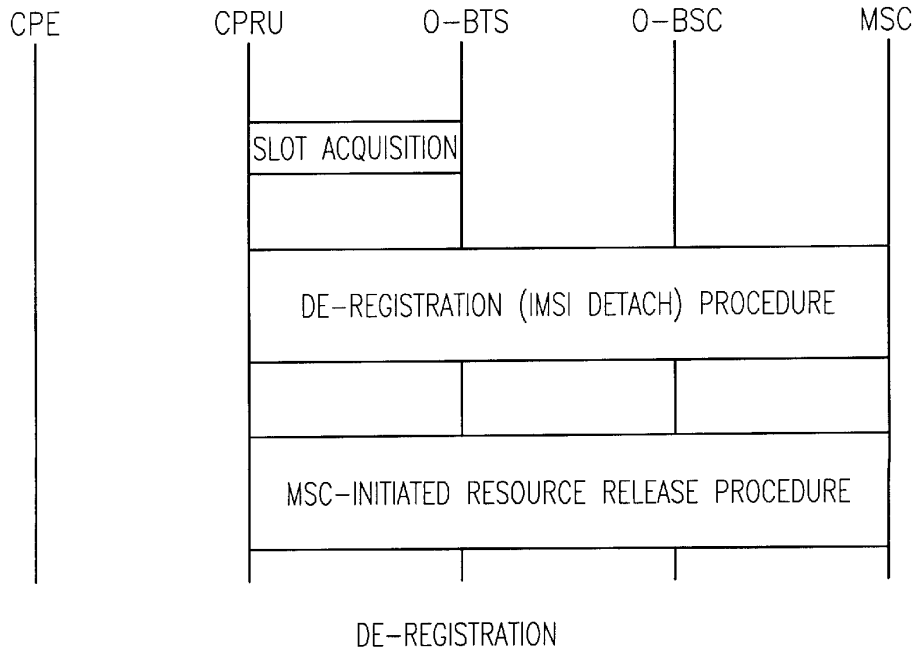

FIG. 13

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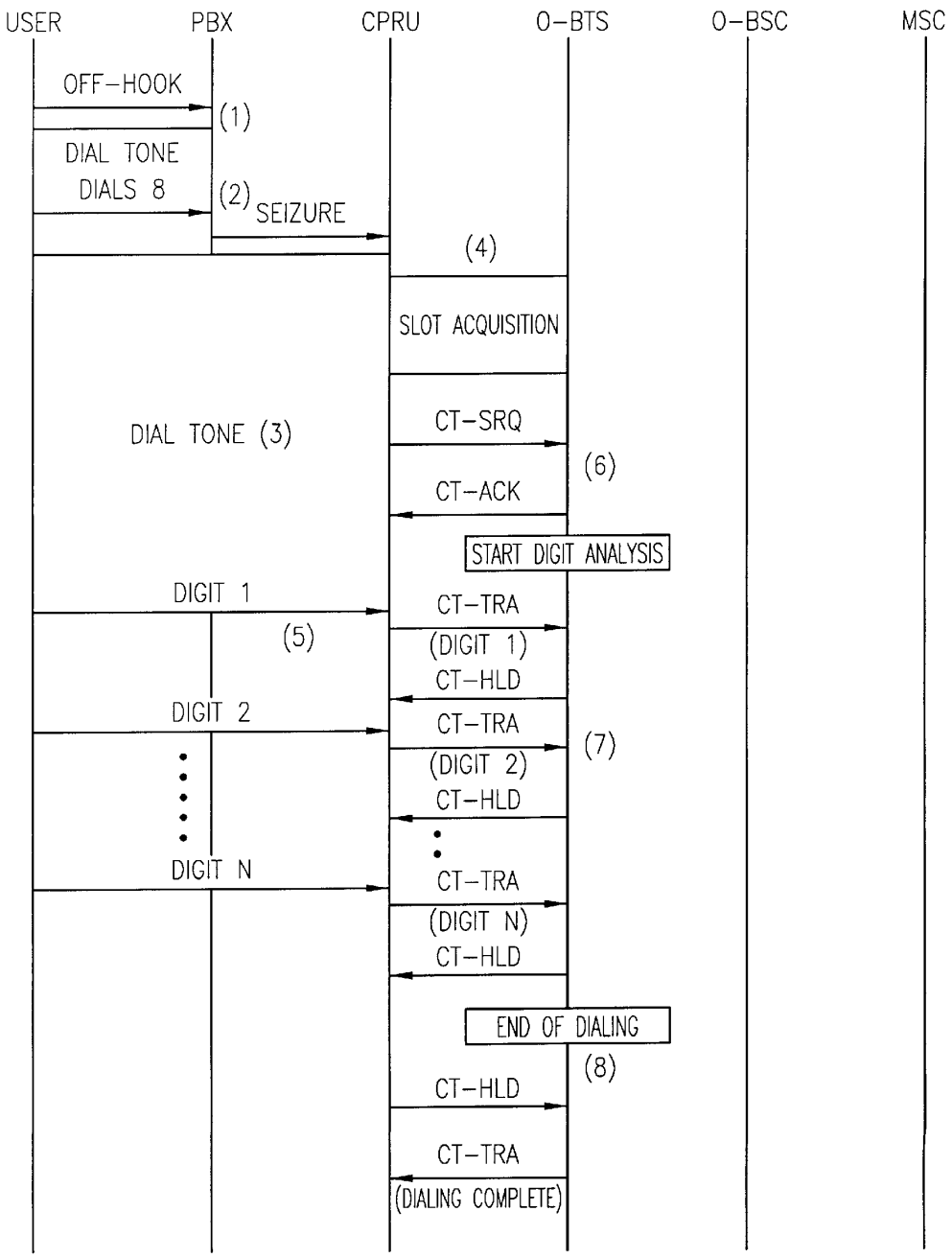

DIAL TONE, DIGIT TRANSMISSION AND DIGIT ANALYSIS FOR A "DUMB" PBX

FIG. 14

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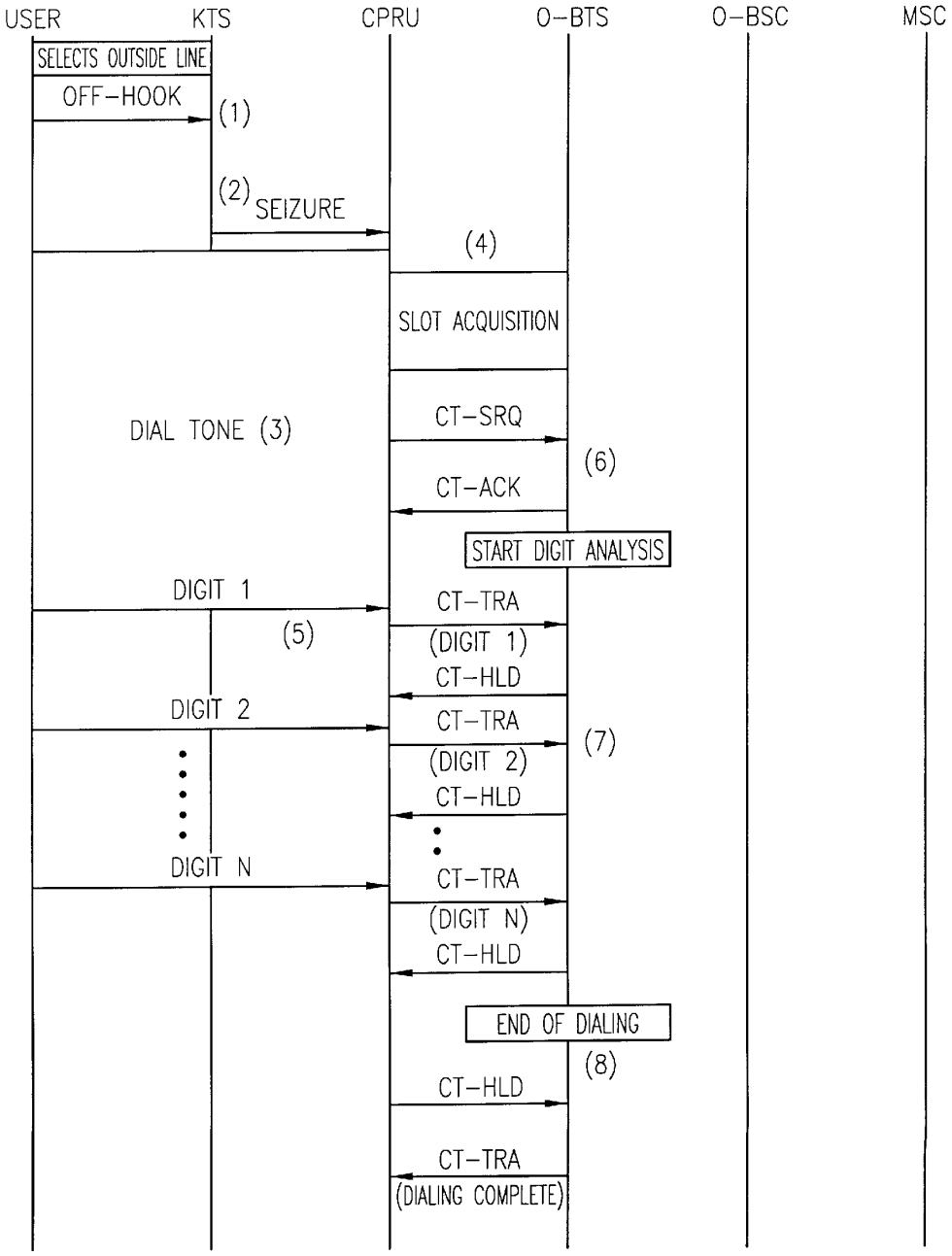

DIAL TONE, DIGIT TRANSMISSION AND DIGIT ANALYSIS FOR A "DUMB" KTS

FIG. 15

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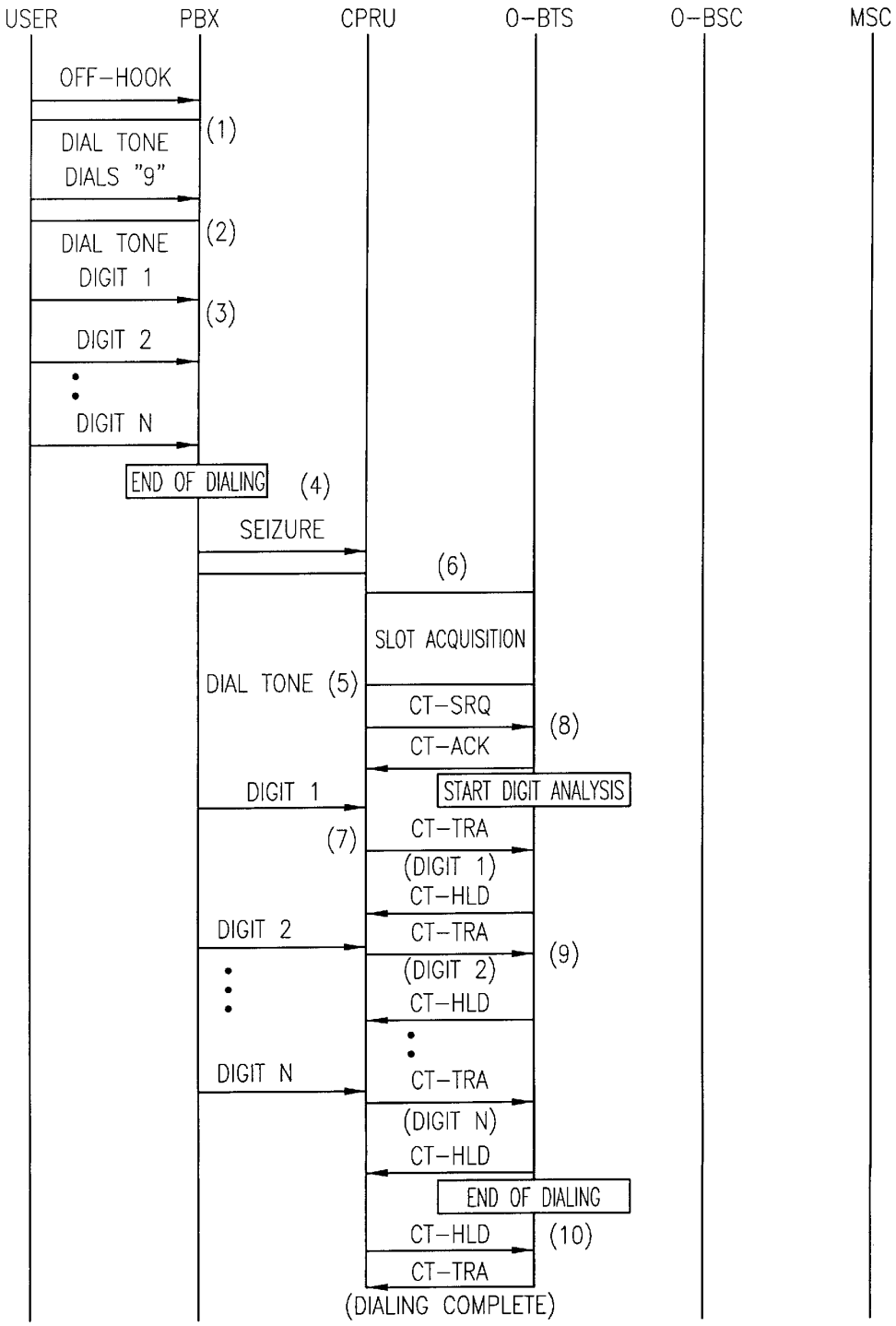

DIAL TONE, DIGIT TRANSMISSION AND DIGIT ANALYSIS FOR A MORE MODERN PBX

FIG. 16

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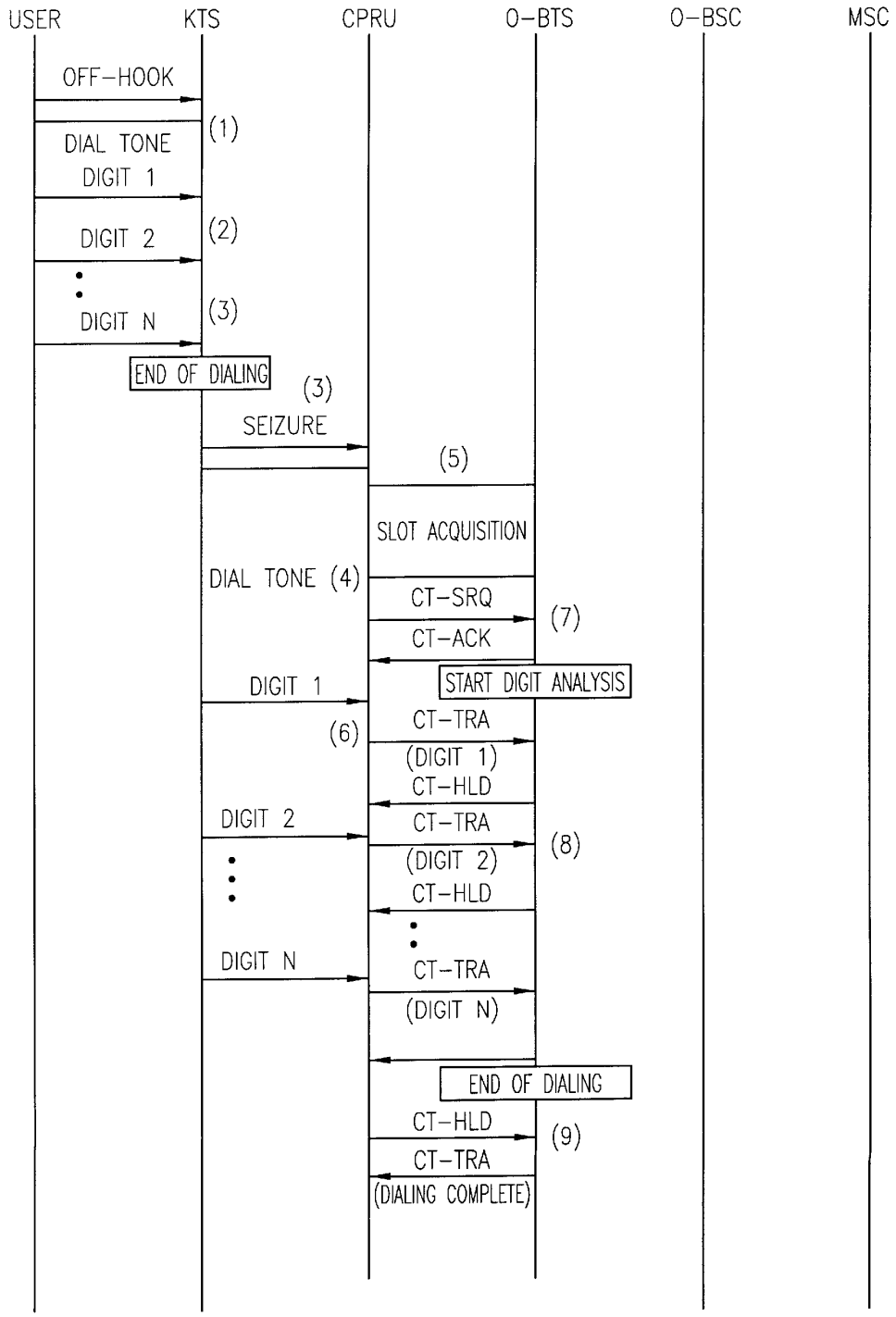

DIAL TONE, DIGIT TRANSMISSION AND DIGIT ANALYSIS FOR A MORE MODERN KTS

FIG. 17

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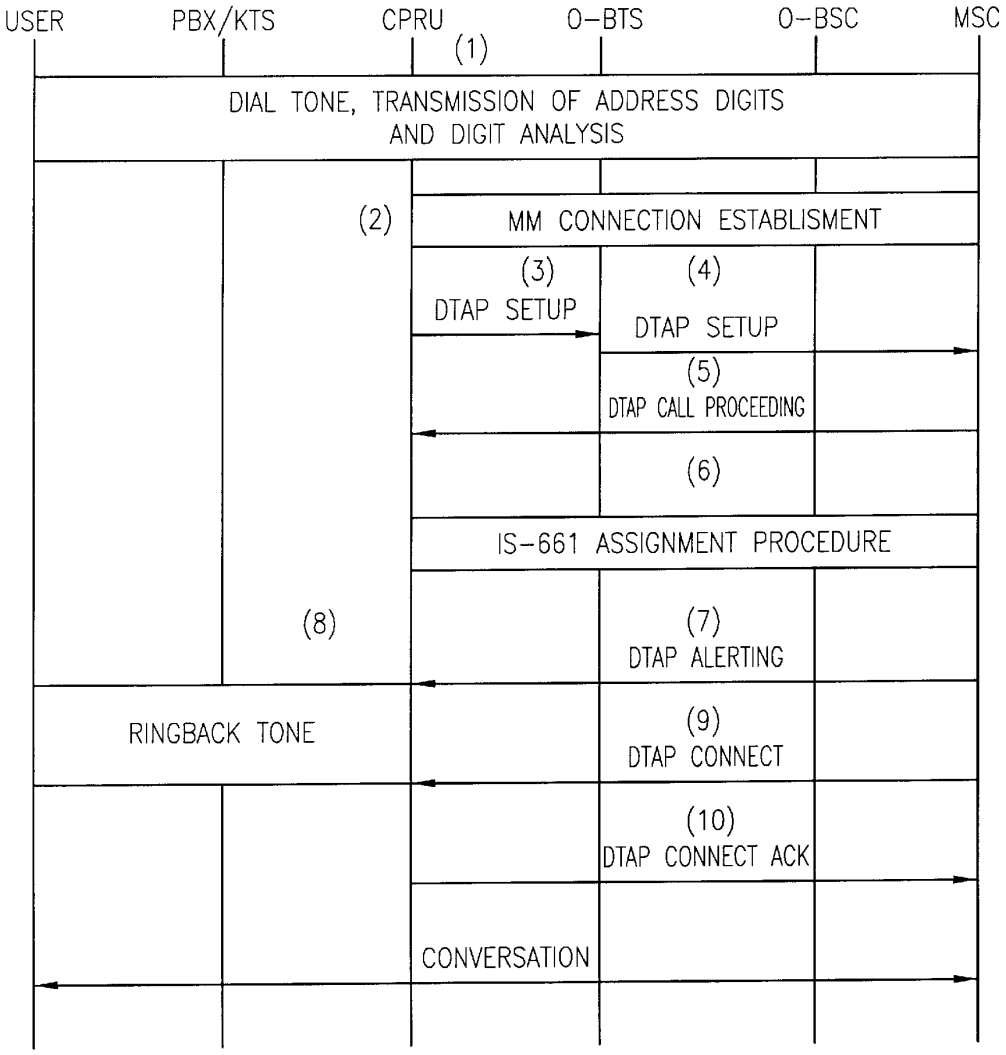

SUCCESSFUL OUTGOING CALL SETUP (NON-PSTN INTERWORKING)

FIG. 18

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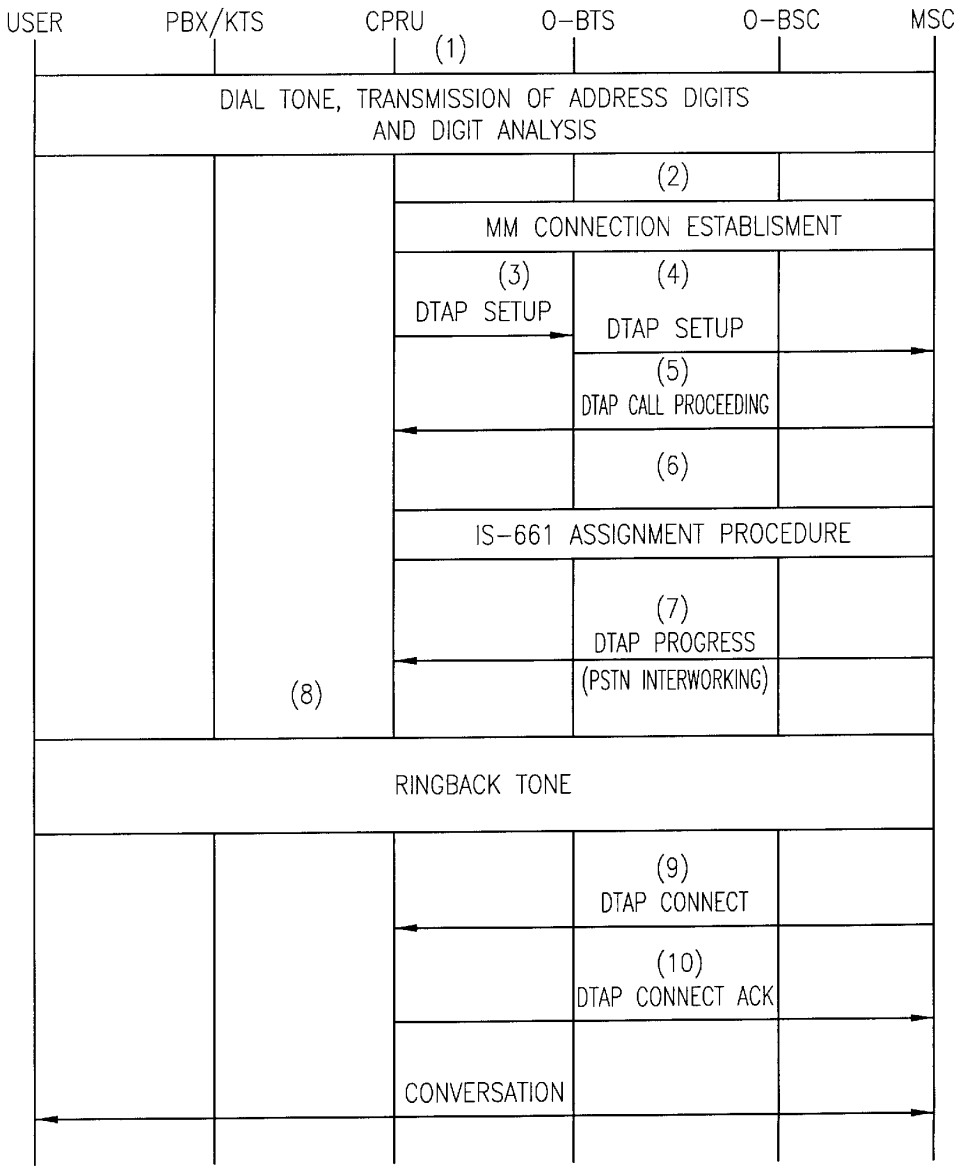

SUCCESSFUL OUTGOING CALL SETUP (PSTN INTERWORKING)

FIG. 19

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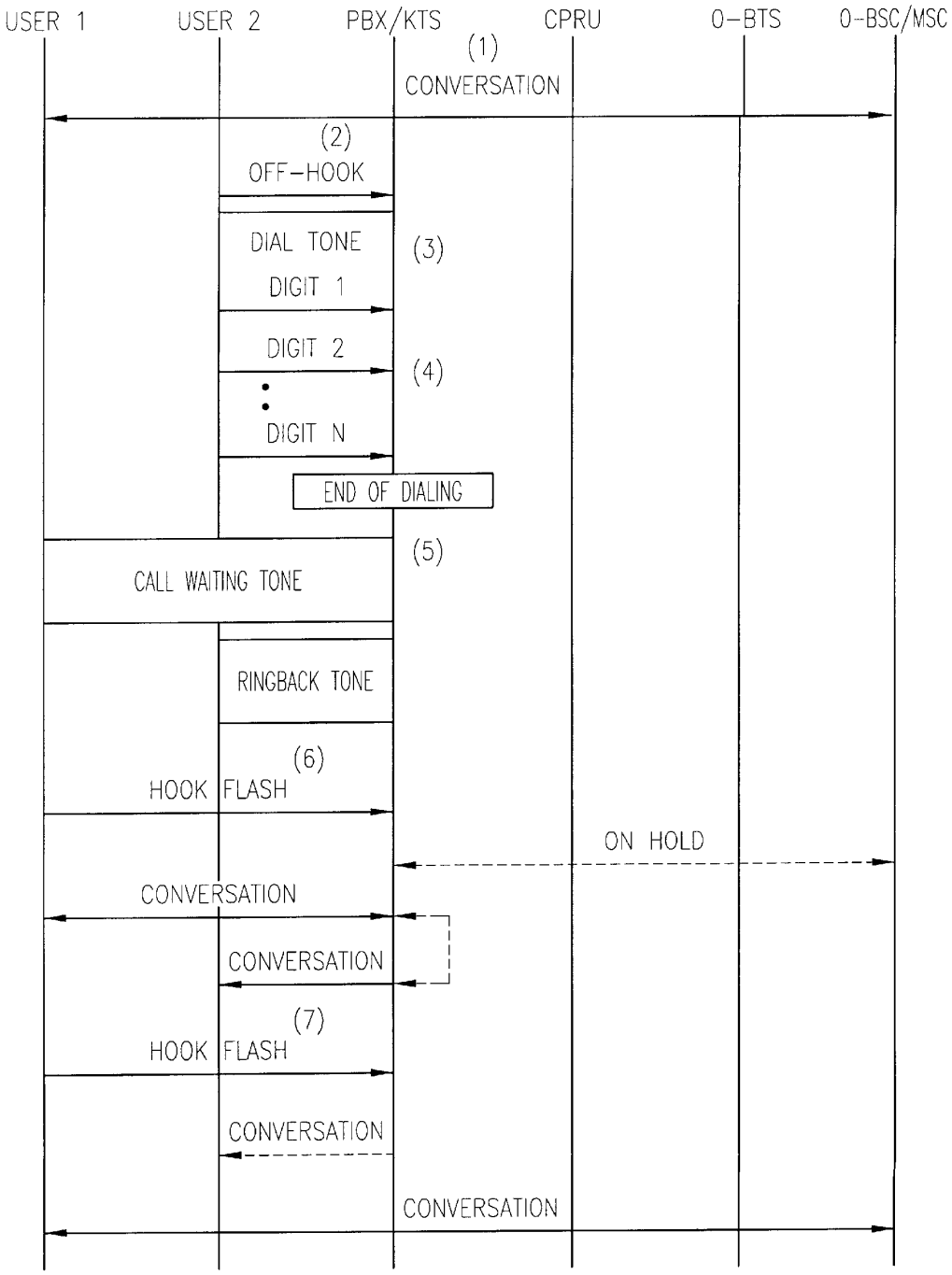

CALL WAITING SCENARIO

FIG. 20

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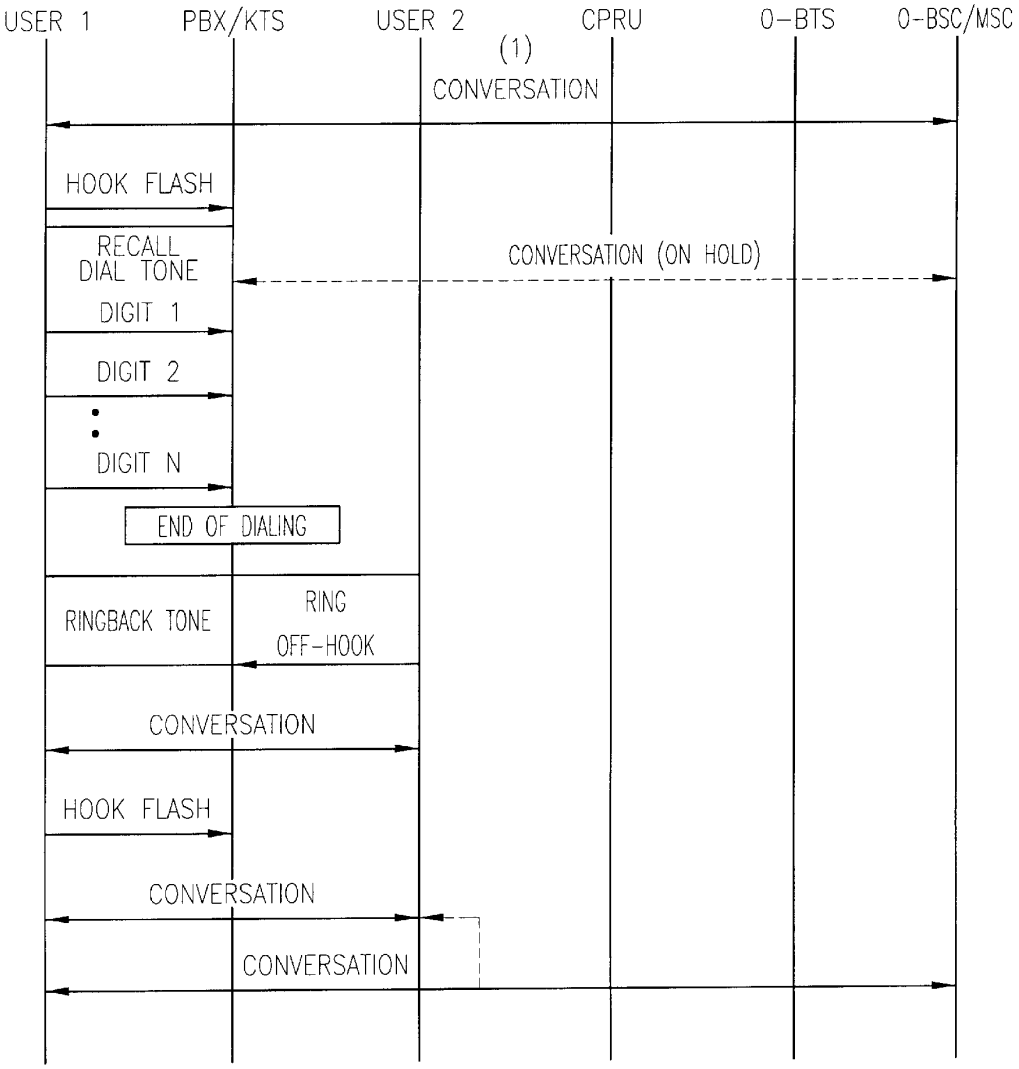

THREE-WAY CALL SETUP SCENARIO

FIG. 21

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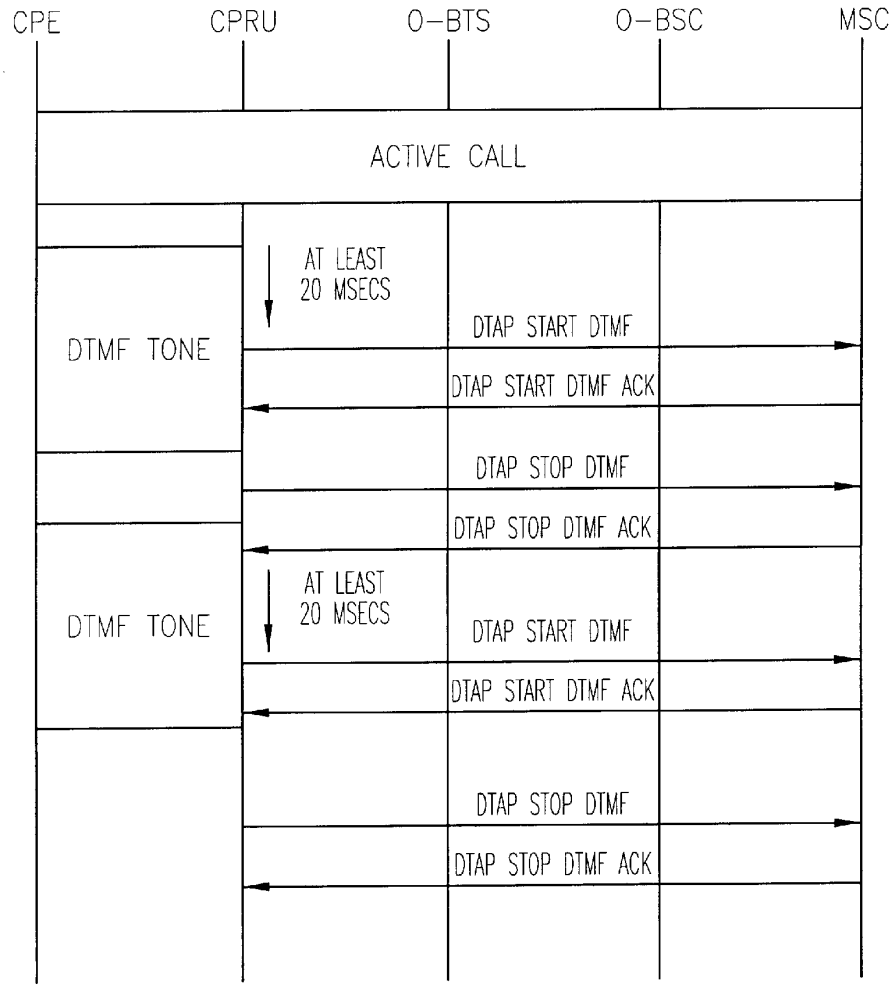

DTMF TRANSMISSION

FIG. 22

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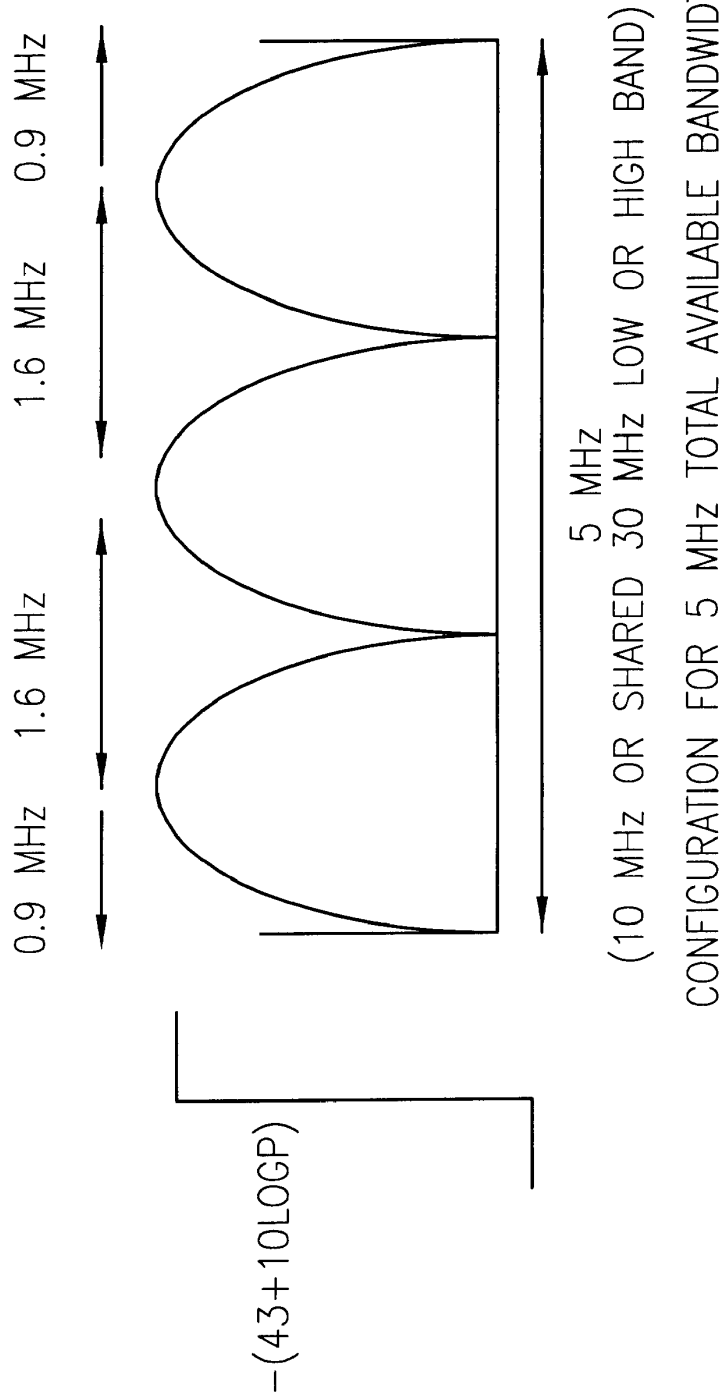

FIG. 23

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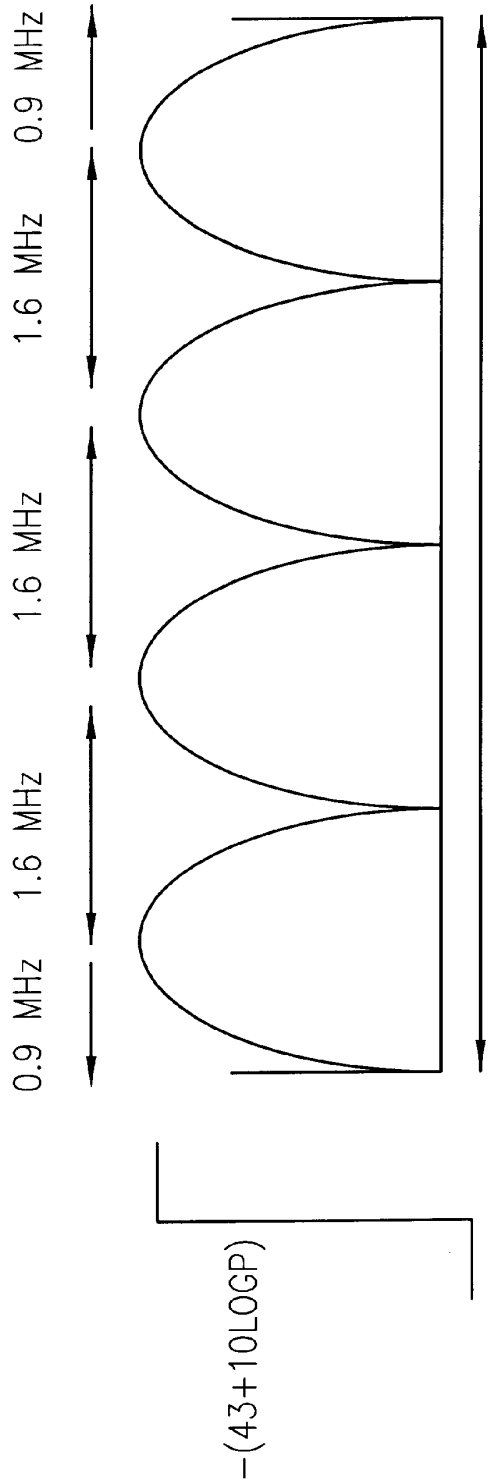

FIG. 24

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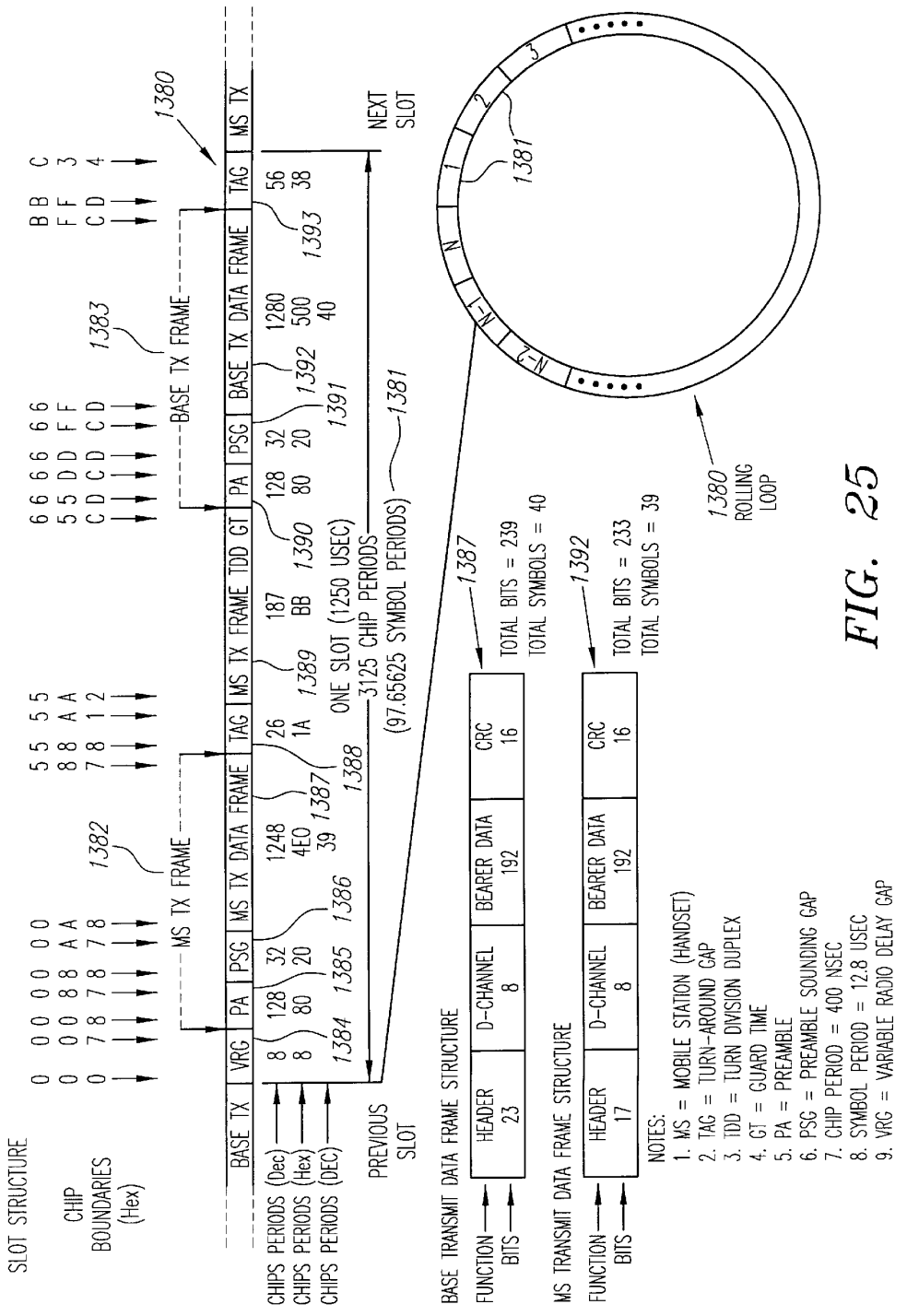

FIG. 25

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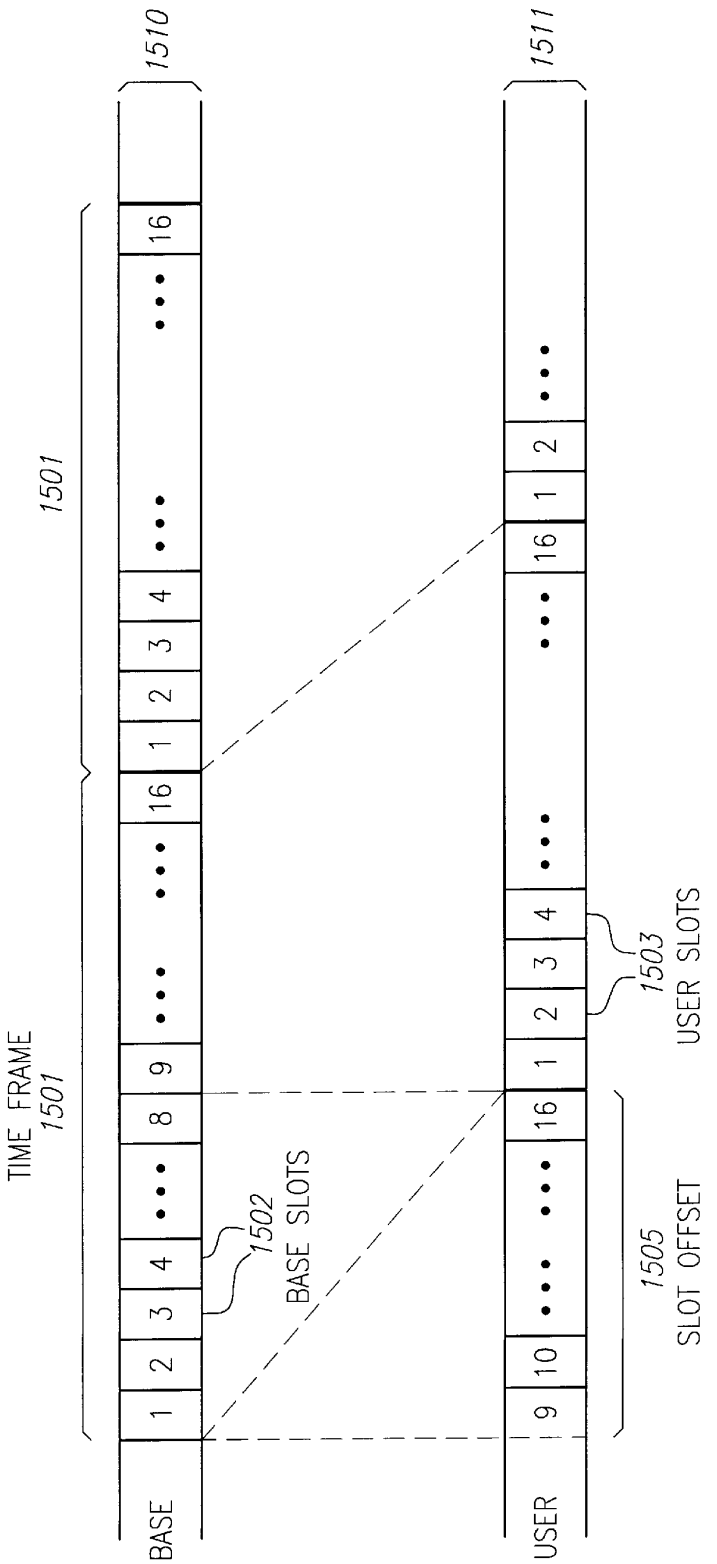

FIG. 26

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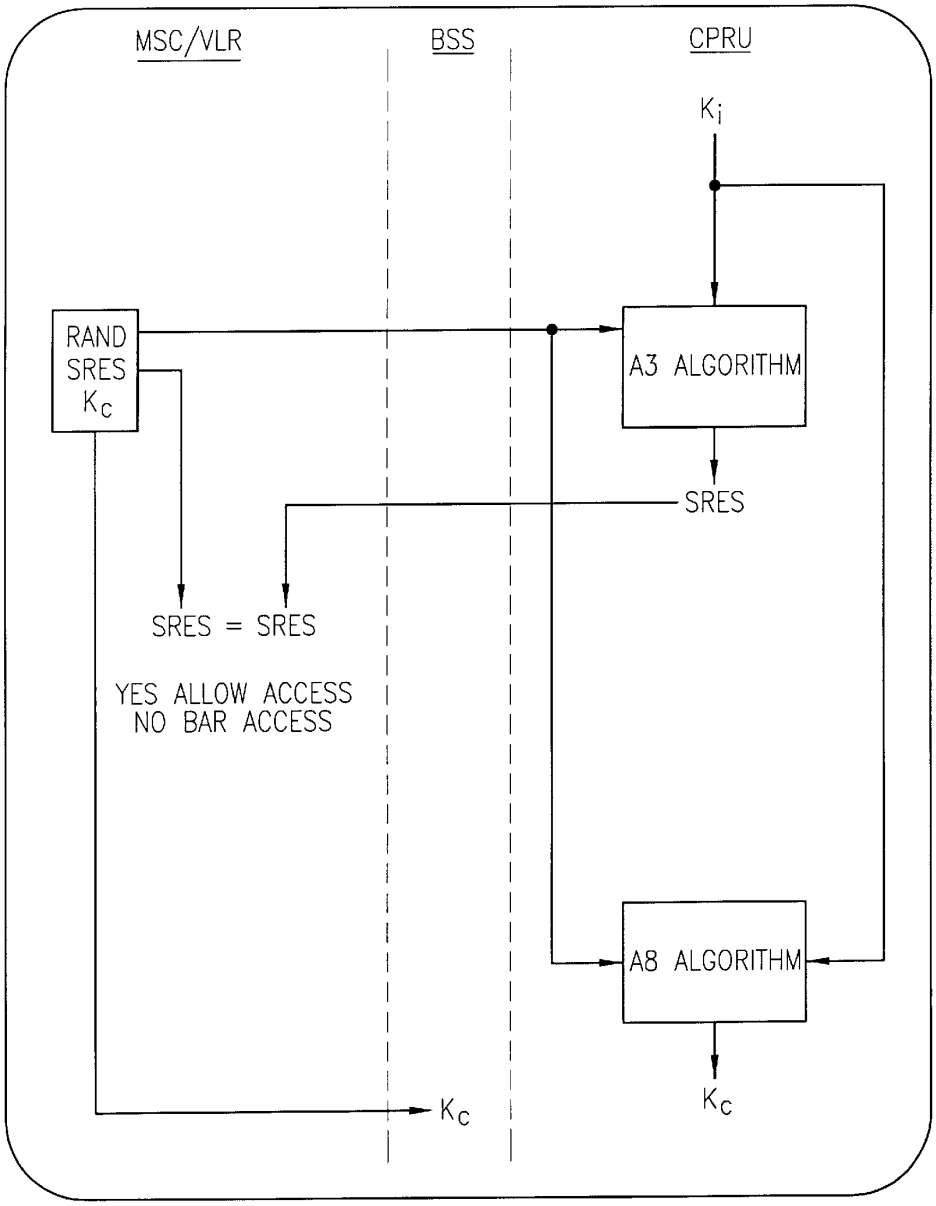

AUTHENTICATION PROCEDURES

FIG. 27

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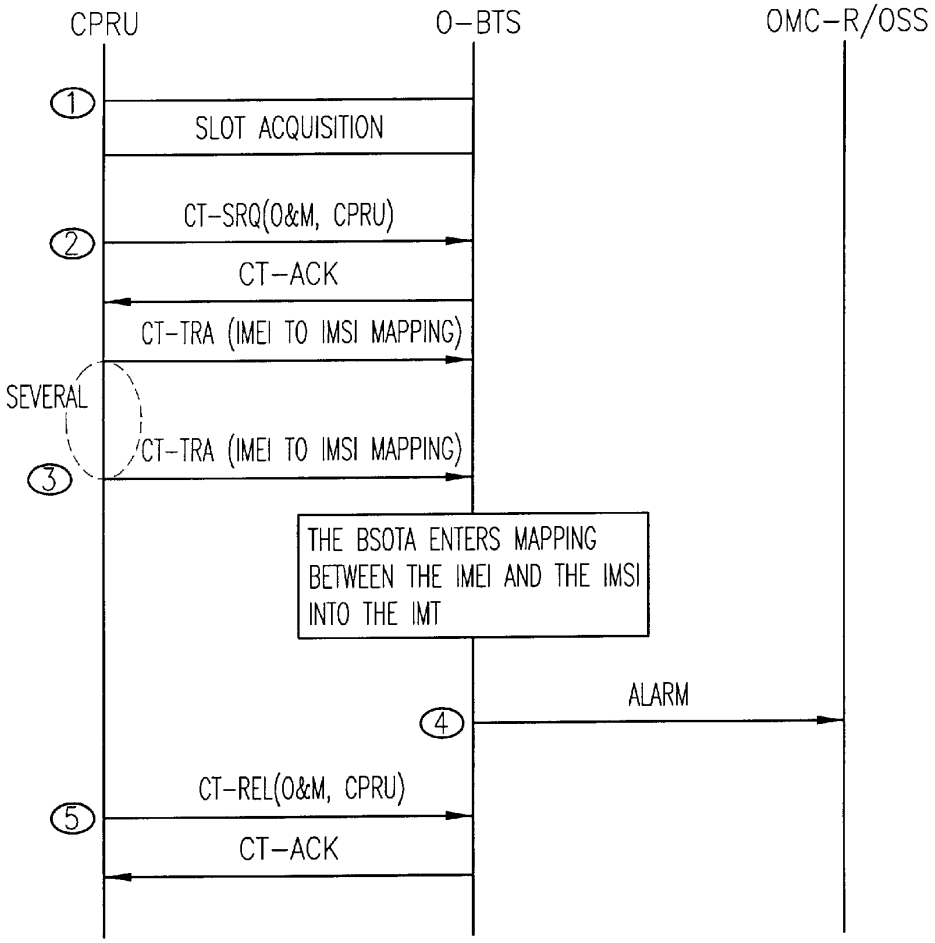

POWER-ON/BASE LEVEL REGISTRATION (GEOGRAPHIC)

FIG. 28

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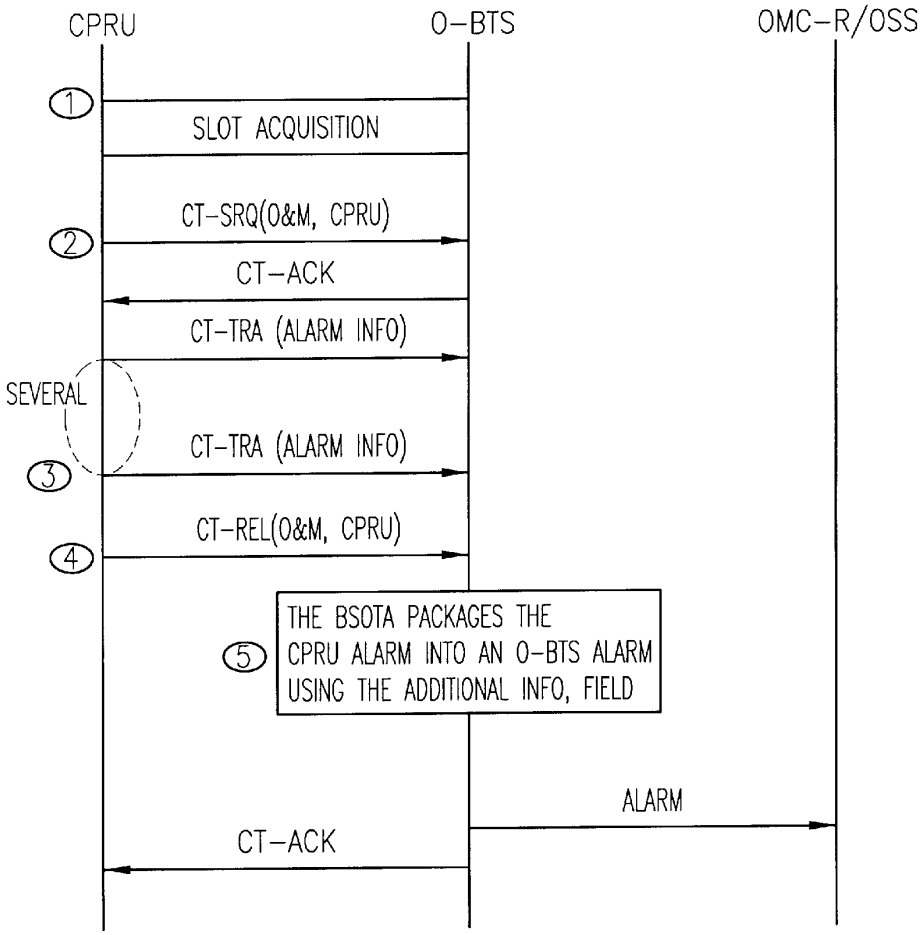

CPRU ALARM REPORTING

FIG. 29

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SIGNALING AND PROTOCOL FOR COMMUNICATION SYSTEM WITH WIRELESS TRUNK

BACKGROUND OF THE INVENTION

1) Field of the Invention

The field of the present invention relates to a method and system for providing communication services.

2) Background

Localized telephone switching systems such as private branch exchanges (PBXs) and key type systems have for many years been available to business offices and other establishments as an alternative or adjunct to public telephone service. A PBX or key system allows users connected to the system to place intra-system telephone calls without accessing the public telephone service. Such a system can provide significant economic benefits, particularly if intra-system telephone traffic is heavy.

On the other hand, when callers using a PBX or key system need to place a call to a party not connected to the system, such outside calls must typically be routed through the PBX or key system controller over landlines to the public telephone company. To accommodate such dual functionality (i.e., intra-system call support and outside call support), special-purpose telephones have been developed for connection to a PBX or key system to allow manual routing of telephone calls. For example, deskset telephones can be provided with buttons corresponding to different telephone lines. By depressing the appropriate button, the user selects between certain designated lines for calls within the system, or different designated lines for calls over the public telephone network.

In other PBX and key systems call routing over the selected lines may be automatic. For example, the user may select an intra-system call or a call over the public telephone network according to the first digit dialed, and the PBX or key system then analyzes the first digit and routes the call to the proper destination using the appropriate vehicle.

While PBX and key systems are useful for providing economical coverage within a private local telephone system, for long distance the PBX users or key system users may still be required to rely on a local exchange carrier (LEC) whose landlines are connected to the PBX. The local exchange carrier then routes the call to along distance carrier. Because the user must pay both the local exchange carrier and long distance carrier for each long distance telephone call, long distance telephone service can be quite costly, particularly if the volume of long distance calls is large.

Besides high costs for long distance service, another potential disadvantage of existing PBX or key telephone systems is that deployment can be difficult or expensive in remote areas. For example, if long distance service or other public network services are required, then deployment of a PBX or key system is generally limited to where landlines have been laid, so that the PBX or key system can have a connection to a local exchange carrier which connects to the long distance provider. If no landlines are present in the desired deployment location, then it can be expensive to connect landlines to provide long distance access for the PBX or key system. Also, conventional PBX or key systems are generally not very mobile where they require an interface with landlines for long distance access or other types of public network services.

There is a need for a communication system having the ability of a PBX or key telephone system to manage local area calls, yet also which can provide access to lower cost, reliable long distance or other network services. There is also a need for a versatile mechanism for allowing PBX or key type systems to achieve relatively inexpensive access to network resources and long distance coverage. There is also a need for a communication system that employs a robust, flexible protocol for providing long distance coverage or other network services to local users of a PBX, key system or other type of local area network.

SUMMARY OF THE INVENTION

The invention provides in one aspect a communication system having a wireless trunk for connecting multiple phone lines over wireless communication links to a cellular network. In one embodiment of the invention, a central telephone switch or customer premises equipment (CPE), such as a private branch exchange or key system, is connected through one or more trunks to a wireless access communication unit. The wireless access communication unit provides the CPE with one or more wireless communication channels to a cellular network. Calls may be selectively routed by the CPE over landlines to a network or, instead, to the wireless access communication unit, thereby bypassing landlines. Multiple wireless access communication units in a geographical region can communicate with a single base station of the cellular network, so long as the base station capacity and current traffic load permit.

In another aspect of the invention, a wireless access communication unit is provided which has multiple trunk interfaces for connection to a CPE, and a radio transceiver for establishing one or more wireless communication links to a cellular network. Each trunk interface is connected to a line card comprising a vocoder and a subscriber interface. A controller interfaces the line cards with the radio transceiver, and assists in the conversion of data from a format suitable for wireless transmission to a format suitable for transmission over the CPE trunk, and vice versa. Data communicated between the wireless access communication unit and the network may be encrypted at the wireless access communication unit and decrypted at the mobile switching center or else at a separate transcoding unit interposed between the mobile switching center and the base station subsystem.

In a preferred embodiment of the invention, the wireless access communication unit operates according to a protocol utilizing aspects of frequency division multiple access (FDMA), time division multiple access (TDMA) and/or code division multiple access (CDMA), whereby communication channels are assigned to the wireless communication unit on a demand basis. In a preferred embodiment, communication between the wireless access communication unit and a base station of the cellular network is carried out over a plurality of wireless duplex communication channels, one channel for each CPE trunk, with base transmissions in time slots on one frequency band and user transmissions (including those from the wireless access communication unit) in time slots on a different frequency band. In such an embodiment, the user time slots may be offset in time from the base time slots, and radio transmissions may be carried out using spread spectrum techniques.

In another aspect of the invention, the wireless access communication unit registers each CPE trunk to which it is connected such that each CPE trunk appears as a subscriber to the network. Each CPE trunk may therefore be addressed by a unique subscriber identifier. The wireless access communication unit preferably utilizes aspects of GSM signaling to communicate information to the network, such that com-

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munication with a GSM-based network is carried out transparently by the wireless access communication unit.

In yet another aspect of the invention, the wireless access communication unit periodically re-registers each of its CPE trunks. The base station receives and monitors the re-registration signals from the wireless access communication unit and, if the re-registration signals are absent for a predefined period of time, issues an alarm message to the network. The wireless access communication unit may be provided with a unique equipment identifier so that the base station can correlate the different wireless links to a single wireless access communication unit.

Further embodiments, modifications, variations and enhancements of the invention are also disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of an overall system architecture in accordance with a preferred embodiment of the present invention.

FIG. **2** is a block diagram of a basic architecture for a wireless access communication unit in accordance with various aspects of the present invention.

FIG. **3** is a diagram of a software architecture for the wireless access communication unit of FIG. **2**.

FIG. **4** is a block diagram of a basic architecture for a base station.

FIG. **5** is a diagram of a software structure for the base station of FIG. **4**.

FIG. **6** is a block diagram illustrating addressing of multiple trunks connected to a wireless access communication unit according to a preferred embodiment of the present invention.

FIG. **7** is a diagram illustrating an interface signaling structure between a base station and a base station controller.

FIG. **8** is an abstract diagram of a system protocol architecture.

FIG. **9** is a diagram illustrating a division of bearer path functions among a wireless access communication unit (CPRU), base station and base station controller components of a preferred communication system.

FIG. **10** is a diagram showing interfaces between the different components of a preferred system.

FIG. **11** is a diagram of multiple wireless access communication units in different location areas connected to a single base station controller.

FIG. **12** is a call flow diagram for a network-level registration procedure.

FIG. **13** is a call flow diagram for a network-level de-registration procedure.

FIG. **14** is a call flow diagram for dial tone, digit transmission and digit analysis for a communication system having a PBX.

FIG. **15** is a call flow diagram for dial tone, digit transmission and digit analysis for a communication system including a key system (KTS).

FIG. **16** is a call flow diagram for dial tone, digit transmission and digit analysis for a communication system having another type of PBX.

FIG. **17** is a call flow diagram for dial tone, digit transmission and digit analysis for a communication system having another type of KTS.

FIG. **18** is a call flow diagram for a successful outgoing call setup without PSTN interworking.

FIG. **19** is a call flow diagram for a successful outgoing call setup with PSTN interworking.

FIG. **20** is a call flow diagram for a scenario involving call waiting.

FIG. **21** is a call flow diagram for a scenario involving three-way calling.

FIG. **22** is a call flow diagram for DTMF tone transmission.

FIGS. **23** and **24** are frequency distribution diagrams illustrating frequency spectrum allocations according to two exemplary embodiments of the invention.

FIG. **25** is a timing diagram of an over-the-air protocol that may be used in the communication system shown in FIG. **1**.

FIG. **26** is a timing diagram of an alternative over-the-air protocol for the communication system shown in FIG. **1**.

FIG. **27** is a diagram showing an authentication process.

FIG. **28** is a call flow diagram illustrating network-level registration.

FIG. **29** is a call flow diagram illustrating alarm reporting.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. **1** is a diagram showing an overall system architecture of a communication system **101** in accordance with a preferred embodiment of the present invention. In the system architecture illustrated in FIG. **1**, a plurality of telephone stations **102** are connected to a central telephone switch **105**. It will be understood that telephone stations **102** could comprise telephones, modems, fax machines, or other devices that are capable of communicating over a completed call connection. The central telephone switch **105** will be referred to herein as a "customer premises equipment" or "CPE." The CPE **105** may comprise, for example, a private-branch exchange (PBX) system or a key system. The design of various types of PBX and key systems is well known in the art.

In the preferred embodiment depicted in FIG. **1**, the CPE **105** is connected to both a public switched telephone network (PSTN) **125** and a wireless access communication unit **106** (also referred to occasionally herein, or in the drawings, as a "customer premises radio unit" or "CPRU"). As described in more detail hereinafter, in a preferred embodiment calls are selectively placed over the PSTN **125** and the wireless access communication unit **106** according to the type of call. The wireless access communication unit **106** communicates over a wireless trunk **108** (which comprises a plurality of wireless communication links) to a base station **109**. The base station **109** is connected, along with other base stations **109** in adjacent or nearby geographical regions, to a base station controller **112**. The base station controller **112** is connected to a transcoding unit **115**, which is connected to a mobile switching center (MSC) **116**. Optionally, the base station controller **112** may be connected directly to the mobile switching center **116**, without the intermediary transcoding unit **115**. The mobile switching center **116** is connected to the PSTN **125**.

In addition to being connected to the transcoding unit **115** or, optionally, the MSC **116**, the base station controller **112** is also connected to an operations and maintenance center (OMC) **120**, which is in turn connected to an operations support system (OSS) **122**. The mobile switching center **116** is connected to a home location register and authentication center (HLR/AuC) **123** and to the operations support system **122**, as shown in FIG. **1**. The base station **109** may also be connected to a local management terminal **121**.

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As further described herein, the invention provides in one aspect signaling techniques and protocols for facilitating communication in a system having a wireless trunk. Signaling information is transported across one or more of the various interfaces of the communication system **101**, so as to allow communication between the CPE **105** and the PSTN **125** to take place utilizing the capabilities of the wireless access communication unit **106**. In a preferred embodiment, the communication system incorporates aspects of the IS-661 communication protocol (or a modified version of the IS-661 protocol) and the GSM communication protocol, thereby employing a "hybrid" protocol. Further details relating to preferred signaling techniques and protocols are described later herein, after a description of some of the basic components of a preferred system including the operation thereof.

In the preferred communication system **101** shown in FIG. **1**, calls may be placed from telephone stations **102** directly over the PSTN **125** (i.e., over a landline connection), or over the wireless trunk **108** to the PSTN **125** by utilizing the wireless access communication unit **106**. When a call is to be initiated at one of the telephone stations **102**, it may be routed either directly to the PSTN **125** or to the wireless access communication unit **106**. The routing of the call may be either based on manual selection, or accomplished automatically based on the number dialed, as further described herein. In a preferred embodiment, local telephone calls are routed directly to the PSTN **125**, while long distance telephone calls are routed through the wireless access communication unit **106**.

Operation of the system shown in FIG. **1** may depend in part on the nature of the CPE **105**. As noted previously, the CPE **105** may comprise, for example, a PBX or a key-type system. In an embodiment where the CPE **105** comprises a PBX, the PBX is preferably capable of routing an outgoing call placed from a telephone station **102** to the PSTN **125** or to the wireless access communication unit **106** based on either an access digit or the telephone number dialed by the user. The user may, for example, dial a certain first digit (e.g., an '8') for access to the wireless access communication unit **106**, and a different first digit (e.g., a '9') for direct LEC access to the PSTN **125**. In this manner, the user could, for example, access the wireless access communication unit **106** to make outgoing long distance telephone calls, or the PSTN **125** for other types of outgoing calls. Alternatively, some types of PBXs can be configured to analyze the dialed number, and to route long distance and local calls. Utilizing this ability, the PBX can be configured to route long distance calls through the wireless access communication unit **106** and local or emergency calls through the PSTN **125**.

In an embodiment where the CPE **105** comprises a key system, the user may manually select a line (either for the wireless access communication unit **106** or the PSTN **125**) by depressing a key on the telephone deskset. The user could, for example, select the call processing unit **106** for outgoing long distance calls, and the PSTN **125** for other types of outgoing calls. Some key systems can, like certain PBXs, be configured to analyze the dialed number, and to route a call either to the wireless access communication unit **106** or the PSTN **125** depending on the initial digits of the call and/or the number of digits dialed. In this manner, the key system can, for example, be configured to route long distance calls through the wireless access communication unit **106**, and local or emergency calls through the PSTN **125**.

In alternative embodiments, the system may be configured with less flexibility but a potentially simpler architecture. For example, the system can be configured such that all incoming calls are routed directly from the PSTN **125** to the CPE **105**, and that all outgoing local calls (whether voice or data), all outgoing long distance data calls, and all TTY calls for persons with disabilities are also routed directly through the PSTN **125**. In such an embodiment, the wireless access communication unit **106** would generally provide outgoing long distance voice communication capabilities.

The CPE **105** is connected to the wireless access communication unit **106** across a CPE trunk interface **104**. The CPE trunk interface **104** comprises a plurality of CPE trunks, each of which may comprise, for example, loop-start trunks or ground-start trunks. The design of both loop-start trunks and ground-start trunks is well known in the art. As is also well known to the practitioner in the art, both loop-start trunks and ground-start trunks can be supported by the same local area switching equipment (i.e., the same PBX or KTS).

In an embodiment in which the CPE **105** comprises a PBX, the PBX preferably has certain operating characteristics. In addition to supporting loop-start trunks or ground-start trunks (or both) on the CPE trunk interface **104** between the PBX and the wireless access communication unit **106**, the PBX also preferably supports DTMF address signaling on the loop-start trunks or ground-start trunks. The PBX may be configured to route calls through either the PSTN **125** or the wireless access communication unit **106**, as described previously, and therefore has the ability to identify which trunks lead to the PSTN **125** and which trunks lead to the wireless access communication unit **106**. The PBX preferably has the ability to specify the order in which the trunk groups are tried when an outgoing call is placed, and to re-route outgoing long-distance calls through the PSTN **125** instead of the wireless access communication unit **106** in case of access problems from the wireless access communication unit **106** to the wireless system.

In an embodiment where the CPE **105** comprises a key telephone system (KTS), the KTS preferably has certain operational characteristics. In addition to being configured to support loop-start trunks or ground-start trunks (or both) on the CPE trunk interface **104** between the KTS and the wireless access communication unit **106**, the KTS also preferably supports DTMF address signaling on the loop-start trunks or ground-start trunks, and has the ability to route calls through either the PSTN **125** or the wireless access communication unit **106**, as described above. While not essential, the KTS may also be provided with supplementary call support features and a route selection feature (i.e., the ability to identify trunk groups leading to the wireless access communication unit **106** and the PSTN **125**, and to specify on the KTS the order in which the trunk groups should be tried). If a route selection feature is provided, the KTS should have the ability to re-route outgoing long-distance calls through the PSTN **125** instead of the wireless access communication unit **106**, in case there are access problems from the wireless access communication unit **106** to the wireless system.

The wireless access communication unit **106** acts as the gateway for wireless trunk access to the CPE **105** via the wireless system, and correlates the individual CPE trunks with wireless communication links such that calls from the CPE **105** can be completed over a wireless network. FIG. **6** is a diagram illustrating an embodiment of a wireless access communication unit **605** connected to a CPE **105** (see FIG. **1**) across a plurality of CPE trunks **602** (in this example, four CPE trunks **602**). The wireless access communication unit **605** also is connected over a plurality of wireless commu-

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nication links (or "pipes") **609** to a wireless network and, in particular, to a base station (not shown in FIG. **6**). The wireless access communication unit **605** establishes the wireless communication links **609** and correlates therewith the CPE trunks **602**, so that communication for a particular CPE trunk **602** is carried out over an assigned wireless communication link **609**. Users connected to the CPE **105** can obtain access to the wireless access communication unit **605** (and, hence, to the wireless network) by being connected through the CPE **105** to one of CPE trunks **602**. In this manner, a potentially large number of users connected to the CPE **105** can have the ability to complete calls to the wireless network, with the number of users able to make calls simultaneously equaling the number of CPE trunks **602** (and wireless communication links **609**) available.

Various components of the communication system shown in FIG. **1** will now be described in more detail. In addition, a detailed description of the preferred system interworking, protocols and related information appears hereinafter, and also appears in copending U.S. patent application Ser. Nos. 08/987,957, 08/988,482, 08/988,505, 08/987,872, and 08/987,893, and U.S. Pat. 6,097,817 each of which is field concurrently herewith, and each of which is hereby incorporated by reference as if set forth fully herein.

The wireless access communication unit **106**, as noted, acts as the gateway for the CPE **105** to the wireless network, and preferably performs a variety of functions. In a preferred embodiment, the wireless access communication unit **106** performs off-hook detection for outgoing calls and supports provision of a dial tone to the CPE **105** (and thereby to the telephone station **102** initiating the call). The wireless access communication unit **106** also initiates acquisition of a wireless communication channel (such as an over-the-air time slot, for example, if the wireless network is a TDMA and/or TDD system), and initiates call control procedures. During call establishment, the wireless access communication unit **106** detects dialed address digits (i.e., DTMF tones) and passes the received digits via call control signaling to the network. The wireless access communication unit **106** decides whether to launch a normal or emergency call depending upon an end-of-dialing indication received from the base station **109** indicating the type of call (based on digit analysis performed at the base station **109**). In addition, the wireless access communication unit **106** detects off-hook transitions from the CPE **105**, and initiates call release procedures towards the network in response to an off-hook transition. When a call is completed, the wireless access communication unit **106** provides landline-transparent control of disconnect procedures for clearing initiated by the CPE **105**. As part of this function, the wireless access communication unit **106** implements the release guard times supported by conventional wireline systems.

In addition to the above functions, the wireless access communication unit **106** also supports the signaling of DTMF digits during an active call. As part of this function, the wireless access communication unit **106** detects DTMF tones from the CPE **105** during an active call and relays the digits to the network via DTAP signaling. Also during a call, the wireless access communication unit **106** may pass call progress tones received from the network transparently over the bearer path to the CPE **105**. Whenever call progress DTAP signaling is received from the network, the wireless access communication unit **106** converts the call progress DTAP signals into call progress tones towards the CPE **105**. The wireless access communication unit **106** may generate reorder tones to the CPE **105** when needed, so as to indicate congestion of the wireless network or permanent signal timer expiry conditions to the CPE **105**.

Additionally, the wireless access communication unit **106** also preferably performs a number of functions related to bearer processing. For example, in a preferred embodiment the wireless access communication unit **106** performs vocoding for voice communication. In this regard, vocoding includes encoding/compression of speech towards the network and decoding/de-compression of speech in the reverse direction (i.e., towards the CPE **105**). The wireless access communication unit **106** also preferably performs forward error correction (FEC), encryption and decryption for the bearer voice (with the wireless access communication unit **106** and transcoding unit **115** being peer-to-peer endpoints for ciphering), and echo cancellation functions. For encryption and decryption, the wireless access communication unit **106** encrypts the bearer data prior to transmission over the air (i.e., over the wireless trunk **108**), and decrypts bearer data received from the network. Echo cancellation functions are supported by the wireless access communication unit **106** so as to suppress the echo potentially generated towards the wireless network if, for example, a 2–4 wire hybrid structure is present at the interface with the CPE **105**.

In a preferred embodiment, the wireless access communication unit **106** in conjunction with the wireless system supports management and security features such as call registration, de-registration, user authentication, ciphering of bearer information, and network management functions. In addition to providing a means for outgoing voice calls, the wireless access communication unit **106** may also support outgoing emergency (i.e., "911") calls and end-to-end DTMF signaling during active calls.

Details of a preferred wireless access communication unit **201** are depicted in FIG. **2**, and of a preferred software structure for the wireless access communication unit **201** in FIG. **3**. As shown in FIG. **2**, the wireless access communication unit **201** comprises a plurality of subscriber ports **203**, which are provided for connecting the CPE **105** (see FIG. **1**) to the wireless access communication unit **201** across a trunk interface (e.g., trunk interface **104** shown in FIG. **1**). Each subscriber port **203** can support one call connection over the wireless access communication unit **201**, and may comprise, for example, an RJ-11 interface. While four subscriber ports **203** are shown in FIG. **2**, it will be understood that the number of subscriber ports **203** may vary depending upon the particular application or environment in which the wireless access communication unit **201** is deployed. For example, the wireless access communication unit **201** may be configured with only a single subscriber port **203**, or may have any number of subscriber ports **203** limited only by practical considerations such as the number of wireless communication channels generally accessible and available to the wireless communication unit **201**. Also, the subscriber ports **203** may comprise any suitable interface, with an RJ-11 interface being but one example of such an interface.

Each subscriber port **203** is connected to an individual line interface unit or line card section **205**. Thus, the wireless access communication unit **201** comprises four line card sections **205**, one for each subscriber port **203**. The line card section **205** provides a physical subscriber line interface from the CPE **105** to the wireless access communication unit **201**, and in addition provides digitizing and data compression functions.

Details of one of the multiple line card sections **205** are shown in FIG. **2**, with the other line card sections **205** being configured in a similar fashion. The line card section **205** comprises a subscriber interface **207** which is connected to one of the subscriber ports **203**. The subscriber interface **207** comprises a subscriber line interface circuit (SLIC) **217**,

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which provides conventional loop interface functions including battery feed, overload protection, supervision, and 2–4 wire hybrid. Both loop-start and ground-start signaling are preferably supported by the line card section **205**. The selection between loop-start and ground-start signaling may be made, for example, by use of a manual toggle switch or dip switch (not shown) located on the wireless access communication unit **201**, each line card section **205** may be individually configured to interface with a loop-start or ground-start trunk. The subscriber interface **207** further comprises a standard CODEC or, alternatively, a subscriber line audio processing circuit (SLAC) **215** which carries out analog-to-digital and digital-to-analog conversion between the line card section **205** and the user station (e.g., telephone station **102** shown in FIG. **1**) connected to the subscriber port **203**. The CODEC or SLAC **215** provides a standard μ-law pulse code modulation (PCM) interface. The subscriber interface **207** also comprises a ring generator **216** for generating a ringback tone.

A digitized data stream is output from the CODEC or SLAC **215** and provided across signal line(s) **214** to a vocoder **206**, which compresses the digitized data stream into a compressed data signal. The vocoder **206** comprises a relatively high-speed digital signal processor **211** (operating at, e.g., a rate of twenty million instructions per second or other suitable rate), along with support modules such as a high-speed static random-access memory (SRAM) **212** and an EPROM **213**. The vocoder **206** preferably provides, as part of its decoding function, an interpolation capability for deriving predicted speech patterns, so as to handle situations where, for example, the wireless access communication unit **201** detects data frames that contain errors, or else the data frames contain errors that cannot be corrected by forward error correction (FEC). The decoding function of the vocoder **206** also preferably provides a mute capability for silencing the output to the CPE **105** when beneficial to do so, such as during control traffic exchanges. The vocoder **206** outputs a compressed data signal at a rate of, e.g., 8 Kbps, which is sent to a control line card assembly (LCA) **226** located in a control section **220**. Control section **220** thereby receives four compressed data signals, one from each of the line card sections **205**.

Each line card section **205** also hosts a subscriber interface module (SIM) **208**. The general functions of the SIM **208** are to provide system security and store subscriber-specific information, including such things as subscriber authentication information and subscriber-specific data. In a preferred embodiment, the SIM function is duplicated for each CPE trunk supported by the wireless access communication unit **201**, as each CPE trunk may be viewed as a different subscriber by the network. This duplication may be explained with reference to FIG. **6**. In FIG. **6**, a plurality of CPE trunks **602** are shown connected to the wireless access communication unit **605** (each CPE trunk **602** being connected to a subscriber port **203** shown in the more detailed diagram of FIG. **2**). A separate SIM **606** is associated with each of the CPE trunks **602**. Thus, for four CPE trunks **602**, the wireless access communication unit **605** comprises four SIMs **606**. The wireless access communication unit **605** further comprises a plurality of radio interface units **607**, one for each of CPE trunk **602**, for the purpose of passing data and other information to the wireless transceiver (not shown) which handles the physical wireless communication links **609**.

Generally, each subscriber within the communication system requires unique identification and possibly different system parameters. To the extent that the multiple CPE trunks (corresponding to the multiple subscriber ports **203** shown in FIG. **2**) are viewed by the system as individual and unique subscribers, each CPE trunk is associated with a unique identifier and, preferably, unique authentication and other system parameters, which are implemented at least in part with the separate SIM **208** used in each line card **205**. Thus, for four CPE trunks (corresponding to the four subscriber ports **203** shown in FIG. **2**), four copies of the SIM **208** are used in the wireless access communication unit **201**.

The functionality of the SIM **208** may be implemented as one or more non-removable SIM chips within the wireless access communication unit hardware architecture. The SIM **208** stores within a non-volatile memory (such as a ROM, or non-volatile RAM) subscriber information such as a subscriber identifier. In a preferred embodiment, the subscriber identifier comprises an international mobile subscriber identity (IMSI) number. In addition to storing the subscriber identifier, the SIM **208** also runs an authentication procedure such as, for example, an "A3" and/or "A8" authentication procedure conventionally used in certain GSM applications. Further details regarding authentication may be found in copending U.S. patent application Ser. No. 08/988,505, previously incorporated herein by reference.

The control section **220** of the wireless access communication unit **201** provides timing and control for virtually all aspects of the wireless access communication unit **201**. The control section **220** comprises a processor **225** which may comprise, for example, a 16-bit RISC processor (such as a C165 or C163 processor manufactured by Siemens Corp.) and associated support modules (i.e., SRAM **223**, flash memory, etc.). Access to the SIM **208** is initiated by the host processor **225** and controlled and formatted by the control line card assembly (LCA) in the control section **220**. The processor **225** also coordinates most system activities and moves data between the various modules.

The processor **225** is connected to the control LCA **226** which, as noted above, is connected to the vocoder **206** from each of the line card sections **205**. The control LCA **226** is also connected to a radio interface line card assembly (RIF LCA) **227**. The control LCA **226** provides the interface between the radio section and the line card section of the wireless access communication unit **201**. The control LCA **226** packages and formats data, and coordinates and controls the over-the-air (OTA) protocol. It thereby maintains coordination between up to four compressed serial data streams (one from each of the line card sections **205**) and their respective over-the-air communication channels.

The radio interface LCA **227** is connected to a baseband processor **228**, which may include a digital radio ASIC (DRA) **229**. The baseband processor **228** is connected to a radio section **240**. The radio section **240** preferably comprises a plurality of antennas **243** which are selectable by a selector **242** which is connected to the control LCA **226**. Signals from one or more antennas **243** are thereby provided to a radio transceiver **241** (possibly including multiple radio receivers, one for each antenna **243**). In a preferred embodiment, antenna diversity techniques are utilized such that the wireless access communication unit **201** selects the best antenna (and/or radio receiver) for each frame of time in which it communicates. Various antenna selection techniques are known in the art, or are described in, for example, U.S. patent 6,085,076, hereby incorporated by reference as if set forth fully herein.

The wireless access communication unit **201** may be powered either through an external DC power supply **250** or an on-board battery **251**. The battery **251** may be used as a

reserve power supply, being brought into service automatically if the external DC supply **250** is cutoff or otherwise unavailable. A power section **221** for the wireless access communication unit **201** may comprise local voltage regulators to supply required power to the logic and radio sections, and a switching regulator to supply any requisite loop battery voltage.

The wireless access communication unit **201** may be provided with an LED **231** or other visual display mechanism(s) to indicate the status of the device to an observer. The types of status conditions to be displayed may include, for example, whether the power is on, whether the device is functional (i.e., all self tests have been passed), or whether the device is in service (i.e., is currently registered with a base station).

In operation, compressed serial data is transferred to and from the multiple line cards **205** under the direction of the control LCA **226**. The control LCA **226** places the compressed serial data in a format suitable for the radio interface LCA **227**. It also performs any desired encryption or adds forward error correction information. The control LCA **226** transfers the data to the radio interface LCA **227** which passes the data to the baseband processor **228**. The radio interface LCA **227** keeps track of channel and timing information, and instructs the baseband processor **228** to process the data according to the channel and timing parameters. In a preferred embodiment, the baseband processor **228** comprises a transmitter for formulating continuous phase modulated spread-spectrum signals, or other types of quadrature or related signals, as described, for example, with respect to transmitters shown in U.S. Pat. Nos. 5,629,956, 5,610,940 or 5,548,253, all of which are hereby incorporated herein by reference as if set forth fully herein. At the appropriate time intervals, as determined by the radio interface LCA **227**, the baseband processor **228** sends the data to the radio section **240** which converts the signal to the appropriate transmission frequency and performs any necessary filtering for transmission over the air. The frequency band utilized by the wireless access communication unit **106** is generally dictated by the overall communication system within which the unit is deployed. For example, the frequency band may be within the PCS frequency band of 1930 MHz to 1990 MHz, or may be any other suitable frequency band or bands.

Incoming message signals are received by one or more of antennas **243** and sent to the radio transceiver **241** for downconversion and/or filtering as needed. The downconverted and/or filtered data is then sent to the baseband processor **228** which demodulates the received signal. In a preferred embodiment, the wireless access communication unit **201** transmits and receives messages using a spread spectrum format. In such an embodiment, the baseband processor **228** preferably comprises a spread spectrum correlator. A wide variety of spread spectrum correlators are known in the art, examples of which include embodiments illustrated or described in U.S. Pat. Nos. 5,629,956, 5,610,940, 5,396,515 or 5,499,265, each of which is hereby incorporated by reference as if set forth fully herein.

The baseband processor **228** outputs, among other things, a received signal strength indicator (RSSI), which is used by the control LCA **226** in selecting the best antenna **243** (and/or radio receiver) for reception of the incoming signal. After spread spectrum correlation, the baseband processor **228** provides a stream of data bits to the radio interface LCA **227**, which transfers the data to the appropriate line card **205** based upon the over-the-air communication channel over which the data was received. The data is then processed by the line card **205** and sent to the CPE **105** via the particular subscriber port **203** connected to the line card **205**.

A diagram of a preferred software structure for the wireless access communication unit **201** is shown in FIG. **3**. As shown in FIG. **3**, the software of the wireless access communication unit **201** is functionally divided into two main components, based on the physical interfaces supported by the wireless access communication unit **201**. These two main components are referred to in FIG. **3** as the line manager **350** and the over-the-air manager **351**.

The line manager **350** generally handles the CPE trunk management and communication between the wireless access communication unit **201** and the CPE **105**. In addition to CPE trunk management and communication interface functions, the line manager **350** is also responsible for call signaling, DTMF recognition, and transfer of collected DTMF digits to the over-the-air manager **351**. The line manager **350** comprises a plurality of line drivers **303** and a plurality of SIM drivers **304**, one line driver **303** and one SIM driver **304** for each CPE trunk supported by the wireless access communication unit **201**. A single line driver **303** and SIM driver **304** collectively comprise a CPE line software component **302**.

The over-the-air manager **351** handles the communication interface and link management to the base station **109** (see FIG. **1**). The over-the-air line manager **351** is also responsible for receiving DTMF digits from the CPE **105** (via the line manager **350**) and relaying the DTMF digits to the base station **109** (which ultimately conveys them to the PSTN **125**), as set forth in more detail copending U.S. patent application Ser. No. 08/987,983, previously incorporated herein by reference. The over-the-air line manager **351** also implements the over-the-air communication protocol, including end-to-end communication with various network entities such as the base station controller **112** and mobile switching center **116** (shown in FIG. **1**). Exemplary over-the-air communication protocols that may be implemented by the over-the-air manager **351** include, for example, the GSM direct application transfer part (DTAP) protocol, or the IS-661 over-the-air ("O-Notes") protocol as described in the OMNI_Notes_RMT Protocols Rev. 02.03D (release date Jun. 30, 1997), appearing as a Technical Appendix A filed herewith, and hereby incorporated by reference as if set forth fully herein. At the physical radio level, the over-the-air manager **351** of the wireless access communication unit **201** preferably implements the IS-661 protocol as set forth in the above-referenced OMNI_Notes_RMT Protocols publication, or a variation thereof.

As further illustrated in FIG. **3**, the over-the-air manager **351** comprises a plurality of CPE line link objects **310**, one for each CPE trunk (i.e., subscriber port **203**) supported by the wireless access communication unit **201**. Each CPE line link object **310** provides the signaling resource for a single CPE line or trunk, and comprises several components which together form a signaling protocol stack. The components of the signaling protocol stack work together to interface with a CPE line to provide call management, mobility management and radio resource functionality required to complete a voice call, and the registration functionality required to utilize network resources.

Each CPE line link object **310** comprises a CPE line manager **311**, the purpose of which is to interface with the CPE line software component **302** for the appropriate CPE line or trunk. In a preferred embodiment, the CPE line manager interfaces with a GSM call management component **312** and a GSM call registration component **313**, both

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of which interface with a GSM mobility management component **314**. The GSM mobility management component **314** interfaces with a protocol adaptation (PAL) component **315**, which interfaces with an over-the-air state (OTA) machine **316**. The OTA state machine **316** is generally responsible for managing the physical radio interface, and communicates with the radio transmit/receiver interface and slot management (RTRX) component **321**.

In operation, the CPE line manager **311** signals the GSM mobility management component **314** to initiate connection establishment procedures, as described in more detail hereinafter with respect to the call flow diagrams appearing in FIGS. **13** through **22**. The CPE line manager **311** also controls transmission of DTMF digits to the network, the enabling of the speech path, generation of ringback tones, generation of a busy tone (in non-PSTN interworking situations), and passing of on-hook indication to the CPE **105**. In addition, the CPE line manager **311** manages CPE-initiated call clearing as well as normal and emergency call procedures.

The GSM call management component **312**, GSM registration component **313**, and GSM mobility management component **314** provide a degree of GSM functionality relating to call management, registration, and mobility management, respectively. The protocol adaptation component **315** adapts, if necessary, the GSM signaling protocol to the over-the-air protocol (such as, for example, to the IS-661 over-the-air protocol). The OTA state machine **316** implements the over-the-air protocol and, as noted, manages the physical radio interface.

In addition to the multiple CPE line link objects **310**, the OTA manager **351** further comprises a hardware services component **320** which provides a programming interface to the hardware (including hardware controlled by the line drivers **303** and SIM drivers **304**) of the wireless access communication unit **201**. The OTA manager **351** may comprise a real-time operating system (RTOS) **330**, which may be a multi-tasking operating system, as well as a power-on/reset initialization (POST) component **323** and a debug port manager **322**. The debug port manager **322**, if provided, allows access externally to the internal status of the software, and also permits software downloads.

In addition to the above-described components, the OTA manager **351** also comprises an operations, administration and management (OAM) component **324**. The OAM component runs at the application level, and performs such functions as recognition of faults, creating and sending alarms, and communicating with the line manager **350** for call processing data needed in fault detection and alarms. The types of faults or failures monitored may include, for example, hardware failures (such as power supply failures, radio unit failures, line card failures, and so on), software failures, communication failures, and quality of service failures (e.g., unsuccessful call attempts per time period, time slot interchange requests per time period, unsuccessful time slot interchanges per time period, number of dropped calls per time period, channel quality as indicated by bit error rate, and so on), among others. Fault reporting may be coordinated such that a single fault that causes multiple failures due to the dependency of the software, hardware and telecom functions will result in a single fault being reported.

In one aspect, the functionality of the over-the-air manager **351** used to support the wireless access communication unit **201** may be viewed as a subset or modification of the functionality that would be used to support a mobile user application. For example, the mobility management interface (MMI) software component used in a conventional GSM system to support a mobile user is, in the software architecture shown in FIG. **3**, replaced with a CPE line manager **311**. Another difference over a mobile user application is that a logical instance of the signaling protocol stack is provided for each CPE line connected to the wireless access communication unit **201** (as opposed to having a single logical instance of the signaling protocol stack for a mobile user application), and the SIM driver is modified over a mobile user application to accommodate multiple SIMs (or their logical equivalents) by, for example, the provision of multiple independent SIM drivers **304**. Further, an ability is added to associate a hardware voice path from the CPE **105** with a base station communication link. The signaling protocol may also be modified, as further described herein, to support digit analysis by the base station **109** (see FIG. **1**). DSAT and DTA adaptor software components conventionally used in certain mobile user applications are not needed by the wireless access communication unit **201**, and are therefore not implemented.

Referring back to FIG. **1**, the wireless access communication unit **106**, as noted previously, interfaces with a base station **109** of the wireless system, thereby allowing ultimate access to the PSTN **125**. A block diagram of a preferred base station **401** is shown in FIG. **4**. The base station **401** comprises a number of separate components connected together by a common global bus backplane, as illustrated in FIG. **4**. These components include a digital line card **404**, an over-the-air (OTA) processor card **405**, a power supply module **407**, and a plurality of radio cards **406**, all of which reside on an electronics module **420**. The electronics module **420** is connected to an I/O module **421**, which comprises protection circuitry **403** to prevent such things as damage from short circuits. Each radio card **406** is connected, via the protection circuitry **403**, to one of a plurality of antennas **403**. The digital line card **404** is connected, via protection circuitry **403**, to the PSTN **125** (through base station controller **112** and MSC **116**, as shown in FIG. **1**) over a backhaul line **430**, and possibly to other base stations **109** as well over other physical connections. The base station **401** may be connected to a local AC power supply line **425**, if available.

In operation, the wireless access communication unit (identified by reference numeral **412** in FIG. **4**) transmits over-the-air messages to and receives over-the-air messages from the base station **401**. The multiple antennas **411** and radio cards **406** are used at the base station **401** for achieving antenna diversity. Typically one antenna **411** is selected at a given time for transmitting or receiving over-the-air signals. If spread spectrum communication is being used, then the OTA processor card **405** may comprise a spread spectrum correlator and other baseband processing circuitry for correlating a spread spectrum signal received from the wireless access communication unit **412** and converting it to data bits. The OTA processor card **405** transfers data to the digital line card **404**, which formats the data and sends it over a backhaul to the PSTN **125** via the other intervening system components (such as the base station controller **112** and MSC **116**). Similarly, the digital line card **404** receives data from the PSTN **125**, and transfers the data to the OTA processor card **405** which formats the data for the over-the-air protocol and transmits the formatted data using a selected radio card **406** and antenna **411**.

The primary functions of the radio cards **406** are to transmit and receive RF data packs, to perform packet data integrity services (e.g., cyclic redundancy checks), and to support antenna diversity algorithms. The primary function

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of the OTS processor card **405** is to move bearer data between the radio cards **406** and the digital line card **404**. The OTA processor card **405** also executes operations, administration, management and provisioning (OAM&P) requests from the digital line card **404**, communicates signaling information (using internal base station messages or "I-Notes") with the digital line card **404**, and communicates signaling information (using over-he-air signaling messages or "O-Notes") with the wireless access communication unit **412**. Various types of signaling information and formats therefor (including I-Notes and O-Notes) that may be transmitted across or within the base station **401** or other system components are described in, for example, U.S. patent 6,021,333, hereby incorporated by reference as if set forth fully herein.

The primary functions of the digital line card **404** are to handle link access procedures for the "D-channel" (LAPD) transport on the backhaul line **430**, to exchange bearer data between the OTA processor card **405** and the network-side backhaul components (such as the base station controller **112**), and to multiplex and demultiplex bearer data on the backhaul line **430**. Other primary functions of the digital line card **404** include synchronizing the over-the-air bearer frame timing with the timing on the backhaul line **430** (such as a T1 line), to provide translation between the OAM&P procedures supported on the network and radio interfaces, to map internal base station messages (e.g., I-Notes) to/from the LAPD transport on the backhaul line **430**, and to communicate signaling information (using, e.g., signaling I-Notes) with the OTA processor card **405**.

A preferred high level software architecture for the base station **401** is depicted in FIG. **5**. According to the software architecture shown in FIG. **5**, the software of the base station **401** is split into two functional groups, one functional group relating to the over-the-air functions and the other functional group relating to the line card functions. These two main functional groups are shown in FIG. **5** as the OTA manager **502** and the line card manager **503**, each of which preferably runs on its own processor board. Communication between the OTA manager **502** and the line card manager **503** may be carried out using a dual-port RAM (not shown) physically residing on the digital line card **404**.

Software for the OTA manager **502** and the line card manager **503** may be executed using different processors. For example, in a preferred embodiment, the software for the OTA manager **502** is executed using a MC68430 microprocessor, while the software for the line card manager **503** is executed using a MC68MH360 microprocessor, both of which are manufactured by Motorola Corporation. The microprocessor for the OTA manager **502** is preferably the bus master and has access to the dual-port RAM via the global bus (i.e., the backplane). IS-661 signaling messages in the form of I-Notes and bearer data are transferred across the dual port RAM interface, thereby allowing signaling communication between the OTA manager **502** and the line card manager **503**.

The primary high level functions of the OTA manager **502** are to move bearer data between the dual port RAM and the radio cards **406**, and to handle call control signaling between the line card manager **503** and the wireless access communication unit **412**. Other functions of the OTA manager **502** include radio resource management, terrestrial resource management, and OAM&P support.

The primary high level functions of the line card manager **503** include mulitplexing and demultiplexing bearer data between the dual port RAM and the backhaul line **430** (according to a protocol such as CCITT I.460, for example, if a T1 backhaul line is used), execution of LAPD transport over the backhaul line **430** (using, for example, a Q.921 interface protocol), routing and translation of signaling messages between the OTA manager **502** and the backhaul LAPD, and OAM&P support.

Various interfaces associated with the base station **401** are shown diagrammatically in FIG. **5** as dotted lines, and include an over-the-air interface or "O-interface" **560** between the wireless access communication unit **412** and the base station **401**, an internal interface or "I-interface" **561** between the OTA manager **502** and the line card manager **503**, and a network interface or "N-interface" **562** between the base station **401** and the network-side backhaul components (such as the base station controller **112**, MSC **116**, and PSTN **125** shown in FIG. **1**). Further information regarding these interfaces may be found in U.S. patent 6,021,333, previously incorporated herein by reference, or in copending U.S. patent application Ser. No. 08/988,482, previously incorporated herein by reference. These interfaces are also shown at an abstract level in FIG. **10**, described later herein.

In operation, the base station **401** manages the radio resources for the wireless access communication unit **412**, and thereby provides support for the network side of the wireless trunk **108** (see FIG. **1**). A wide variety of different communication schemes and radio resource protocols may be used. If, for example, the base station **401** implements an IS-661 protocol for over-the-air communication, then the base station **401** manages the resources necessary to support the wireless communication channels between the wireless access communication unit **412** and the base station **401**, including time slots and spread spectrum codes. The base station **401** also provides multiplexing functions for the transfer of data to and from the backhaul line **430** providing the connection to the PSTN **125**. The base station **401** may, for example, multiplex data over a T1 (or fractional T1) backhaul line **430** to the base station controller **112**, which, as noted, pipes the data to and from the PSTN **125** via the MSC **116**.

Protocol signaling over the N-Interface **562**, which connects the base station **401** (or **109** in FIG. **1**) to the base station controller **112** (see FIG. **1**), may be transported using the Q.921 LAPD protocol. Protocol signaling over the O-Interface **560**, which connects the base station **401** to the wireless access communication unit **412**, may be accomplished using over-the-air signaling messages ("O-Notes") according to the IS-661 protocol. The O-Notes may be transmitted along with bearer data in IS-661 RF packets.

Specific software functional components for each of the OTA manager **502** and the line card manager **503** are also depicted in FIG. **5**. The OTA manager **502** comprises a signal processing component **513** and an OTA datalink component **514** which handle the transfer of bearer data for the OTA manager **502**. The signal processing component **513** and OTA datalink component **514** interact with an IS-661 protocol component **512** which implements the IS-661 (or other suitable) over-the-air protocol and contains the protocol state machines for execution of the protocol on the base station **401**. The signal processing component **513** and OTA datalink component **514** thereby deliver bearer data and signaling information in IS-661 packets **541**. The IS-661 protocol component **512** interfaces with an OAM&P component **510** and an I-interface router component **511**, and provides any necessary translation of signaling to the IS-661 protocol.

The line card manager **503** comprises a signal processing component **523** and a bearer datalink component **524** which

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handle the transfer of bearer data for the line card manager **503**. The signal processing component **523** and the bearer datalink component **524** delivers and receives bearer data **552** (in, e.g., an I.460 format) over a T1 backhaul link **533**, which comprises one or more of the T1 time slots available on backhaul line **430**. The line card manager **503** also comprises a LAPD component **522** which delivers and receives signaling messages (e.g., N-Notes) over a LAPD signaling link **551**. Across the N-interface **562**, therefore, two separate information "pipes" are provided, one for signaling and one for bearer traffic, whereas across the O-interface **560** the OTA manager **502** multiplexes the signaling and bearer data onto the radio channels. The LAPD component **522** interfaces with an OAM&P component **520** and an I-interface router component **521**. The I-interface router component **521** of the line card manager **503** communicates with the I-interface router component **511** of the OTA manager **502**, thereby allowing transfer of I-Notes between the line card manager **503** and the OTA manager **502**.

The base station **401** connects and manages radio and terrestrial bearer channels for call-related features, and supports system administration via OAM&P controlled by the system operator through the operations management center **120** (see FIG. **1**). As part of its radio resource management functionality, the base station **401** supports outgoing voice calls (normal and emergency) from the wireless access communication unit **412**. Incoming pages to the wireless access communication unit **412** may optionally be supported by the base station **401**. Because the wireless access communication unit **412** can be embodied as a stationary unit, handoff features otherwise necessary to support mobile user applications do not need to be utilized by the base station **401** to support the wireless access communication unit. However, if the base station **401** employs a protocol utilizing aspects of TDMA, the base station **401** may be configured so as to support time slot interchange (TSI) whereby traffic in time slots experiencing unacceptable levels of interference are relocated to "quieter" time slots. In an analogous fashion, the base station **401** can employ frequency interchange or code interchange, respectively, if aspects of FDMA or CDMA techniques are utilized for the over-the-air protocol.

Among its other radio resource management functions, the base station **401** manages mapping of the radio channels (including the wireless communication channels of the wireless trunk **108**) to the terrestrial (i.e., backhaul) channels. The base station **401** also provides, through its OAM&P functionality, support for administrative state changes, configuration, and provisioning of the radio resources. The base station **401** also provides fault management and alarm management for the radio resources, and sends fault or alarm signals to the base station controller **112**. In addition, the base station **401** provides signaling flow control across the over-the-air interface, power control management for each radio channel, radio link recovery upon radio link interruption, and debug information logs to the base station controller **112**. As part of its power control management for the various radio channels, the base station **401** may send performance metrics relating to the radio resources to the base station controller **112** for analysis.

Subject to capacity and traffic constraints, the base station **401** is generally capable of handling calls from more than one wireless access communication unit **412**, if multiple wireless access communication units **412** are deployed within the service area of the base station **401**. The number of wireless access communication units **412** depends upon the number of wireless channels available at the base station **401** and the amount of traffic at the time call requests are made to the base station **401**. The base station **401** may, if desired, be configured so as to logically associate multiple wireless channels assigned to a particular wireless access communication unit **412**, so as to facilitate such things as de-registration, as further described herein.

With regard to terrestrial resource management, the base station **401** manages and allocates the backhaul channels (such as T1 time slots) over the backhaul line **430**. The base station **401** indicates backhaul channel allocation to the base station controller **112** through signaling messages. In those embodiments in which the wireless access communication unit **106** is non-mobile, the base station **401** need not support handoffs, and therefore need not support re-routing of backhaul channels to accommodate handoffs. The OAM&P component **520** of the base station **401** provides support for administrative state changes, configuration, and provisioning of terrestrial resources. It also provides support for performance metrics of the terrestrial resources, and sends the metrics to the base station controller **112**. The OAM&P component **520** further provides fault management and alarm management for the terrestrial resources, which are also sent to the base station controller **112**. The base station **401** also provides slip management and recovery for T1 backhaul connections, bearer rate adaptation between the radio channels and the backhaul channels, and inband signaling within the bearer data frame to control the transcoder unit **115**.

In terms of call control support, the base station **401** is involved in establishing, maintaining and tearing down outgoing voice calls received from the wireless access communication unit **412**. Preferred call flows pertaining to such functions are shown in, e.g., FIGS. **14** through **19**, and described in more detail hereinafter. The base station **401** also relays DTMF signaling from the end user to the PSTN **125**, if necessary, during an active telephone call. This signaling is relayed transparently through the base station **401**, and is supported by the I-interface and N-interface transport procedures. The base station **401** also provides digit analysis for outgoing telephone calls.

The base station **401** also preferably provides security support in various manners. The base station **401** may, for example, provide support for bearer ciphering that occurs at the transcoding unit **115** and the wireless access communication unit **106**. The base station **401** may also support the GSM temporary mobile subscriber identity (TMSI) for protection of the user identity.

Referring again to FIG. **1**, aspects of the base station controller **112** will now be described. As shown in FIG. **1**, the base station **109** is connected to the base station controller **112** over an interface such as an N-interface (such as the N-interface **562** described previously with respect to FIG. **5**). Data (including signaling messages and bearer traffic) are passed between the base station **109** and the base station controller **112** across the N-interface.

A preferred base station controller **112** may be viewed in one aspect as a base station subsystem controller that is used for managing one or more base stations **109**. A primary responsibility of the base station controller **112** is to provide an interface between the MSC **116** and the radio access subsystem (i.e., the system components responsible for establishing and maintaining the physical radio channels). In a preferred embodiment, the base station controller **112** incorporates aspects of the IS-661 communication protocol and the GSM communication protocol, thereby using what

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may be referred to as a "hybrid" protocol. Details of a preferred communication protocol may be found in, for example, copending U.S. patent application Ser. No. 08/988,482, previously incorporated herein by reference. In an alternative embodiments, the base station controller **112** may be implemented using the IS-661 protocol in its entirety, or the GSM communication protocol in its entirety.

According to the IS-661 protocol, management of the radio resources resides in the base station **109**, with less of a role given to the base station controller **112**. In a GSM-type system, on the other hand, the base station controller **112** plays a greater role in radio resource management, and may be viewed as essentially comprising a compact switch in charge of radio interface management. In the GSM system, the base station controller **112** is configured with intelligence to enable it to instruct the base station **109** and mobile stations (as well as the wireless access communication unit **106**) when to allocate, handoff and release radio channels. The interface between the base station **109** and base station controller **112** in a GSM-type system is referred to as an A_{bis} interface.

In a communication system using a "hybrid" protocol having aspects of both IS-661 and GSM protocols, the base station controller **112** preferably performs a variety of resource management functions. As part of these functions, the base station controller **112** switches bearer circuits and provision of bearer connectivity to form a path from the base stations **109** to the MSC **116** for outgoing voice calls from the wireless access communication unit **106**. In addition to switching bearer circuits, the base station controller **112** provides signaling paths from the wireless access communication unit **106** to the MSC **116** and other network elements. If required, the base station controller **112** carries out the interworking between the BSSMAP radio resource management procedures on the GSM A-interface **571** and the "N-Notes" radio resource management procedures on the N-interface **562**.

The base station controller **112** is involved in the allocation and release of radio channels. If the IS-661 protocol is used, then the base station **109** is the entity that actually assigns and releases over-the-air resources. As part of call setup, however, the base station controller **112** is the entity that coordinates this process. The base station controller **112** also controls the allocation and release of backhaul channels. If the IS-661 protocol is used, then the base station **109** is the entity that actually assigns the bearer resources over the backhaul channels. However, as part of call setup, the base station controller **112** coordinates this process as well.

The base station controller **112** is also involved in ciphering of transmitted data. While the Transcoding unit **115** (see FIG. **1**) is preferably the network end-point for bearer ciphering, the base station controller **112** sets up and coordinates ciphering of bearer messages.

Certain mobility management procedures, such as authentication and identification, run end-to-end between the wireless access communication unit **106** and the MSC **116**, and are relayed through the base station controller **112** with essentially no interworking requirements. For other mobility management functions, the base station controller **112** performs interworking between the N-interface and A-interface procedures. For example, the base station controller **112** may perform interworking between the N-interface and A-interface procedures for location updating or network-level registration (both normal and periodic, as further described herein), de-registration or IMSI detach, time slot interchange reallocation, and mobility management connection establishment.

Call control messages and procedures run end-to-end between the wireless access communication unit **106** and the MSC **116**, and are relayed transparently through the base station controller **112**. In one aspect, the base station controller **112** provides a signaling path between the wireless access communication unit **106** and the MSC **116** to carry out call control signaling.

The base station controller **112** may support a variety of interfaces. The base station controller **112** preferably supports the T-interface to the transcoding unit **115** or, if the transcoding unit functionality is consolidated with the base station controller **112**, a GSM A-interface **571** between the consolidated base station controller/transcoding unit and the MSC **116**. In the other direction, the base station controller **112** also preferably supports the N-interface to the various base stations **109** to which it is connected.

In a preferred embodiment, the base station controller **112** transmits and receives information to the transcoding unit **115**, shown in FIG. **1**. The transcoding unit **115** in one aspect comprises a base station subsystem (BSS) entity located, in one embodiment, between the base station controller **112** and the MSC **116**. Preferably, the transcoding unit **115** is under management control of the base station controller **112**, but is physically located on the premises of the MSC **116**, thereby allowing the base station controller **112** to be remotely located from the site of the MSC **116**. The transcoding unit **115** comprises a number of transcoding unit shelves, operating independently of one another but under the control of the base station controller **112**. In a preferred embodiment, each transcoding unit shelf supports up to 92 bearer channels.

The transcoding unit **115** generally provides the network side processing of key functions on the bearer path. This processing may include, for example, speech transcoding, network-side forward error correction (FEC), and network-side enciphering and deciphering of bearer voice.

With respect to the speech transcoding function, the transcoding unit **115** preferably provides bidirectional conversion between encoded voice data received from the user side, and "mu-law" coded pulse-code modulated (PCM) data received from the network side at 64 kilobits per second. The vocoder **206** in the wireless access communication unit **106** (see FIG. **2**) compresses speech received from the CPE **105** for over-the-air transmission towards the network. In the reverse direction, the vocoder **206** in the wireless access communication unit **106** de-compresses over-the-air speech prior to transmission to the CPE **105**.

The transcoding unit **115** preferably comprises, among other things, a speech encoder and speech decoder. The speech encoder in the transcoding unit **115** receives PCM speech data from the network delivered at 64 kilobits per second, and compresses this data into a sub-rate over-the-air channel for transmission towards the wireless access communication unit **106**. Forward error correction (FEC) information is added separately at the transcoding unit **115** by the FEC function. The speech decoder in the transcoding unit **115** processes compressed speech data from the wireless access communication unit **106**, and transcodes this data to produce 64 kbit/s PCM speech data for transmission towards the MSC **116**. The speech decoder in the transcoding unit **115** additionally provides an interpolate function to output predicted speech patterns, in the event that the base station **109** detects frames that contain errors that are not correctable by the forward error correction function. The speech decoder in the transcoding unit **115** also provides a mute capability for silencing the output to the A-interface when necessary, such as during control traffic transmissions.

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With regard to forward error correction (FEC), in the user-to-network direction the FEC information is added on to messages by the wireless access communication unit **106**. The channel decoding function in the base station controller **112** and/or transcoding unit **115** uses the FEC information to detect the presence of errors, and to estimate the most probable emitted bits given the received ones. In the network-to-user direction, the base station controller **112** and/or transcoding unit **115** applies forward error correction on the frames received from the vocoding function, before the frames are sent across the N-interface. The FEC decoding in the network-to-user direction is performed by the wireless access communication unit **106**.

With regard to encryption and decryption functions, a bearer encryption (or ciphering) mechanism utilized in the system is preferably based on the GSM A5/1 algorithm, which is an algorithm well known in the art. For bearer speech, the two endpoints in the system for encryption and decryption are the wireless access communication unit **106** and the transcoding unit **115**. Where communication is divided into time frames and time slots (such as in certain types of time division multiple access or TDMA systems), encryption and decryption may be performed on a per-frame basis.

The wireless access communication unit **106** and the transcoding unit **115** preferably are "encryption synchronized" in the sense that the frame number used by the wireless access communication unit **106** to encrypt a frame is the same as the frame number used by the transcoding unit **115** to decrypt, and vice versa. The GSM A5/1 algorithm involves the generation of encryption/decryption masks on a per-frame basis, based on the frame number. Typically, establishment or re-establishment of encryption synchronization occurs at call setup and when recovering from loss of encryption synchronization due to error conditions (whether experienced in the over-the-air link or the backhaul link). Once the encryption synchronization is established (or re-established, as the case may be), the wireless access communication unit **106** and the transcoding unit **115** increment the frame number for each frame cycle on the over-the-air and backhaul interfaces. Preferably, the same frame length (e.g., 20 milliseconds) is used for both the over-the-air and the backhaul time frames, so incrementing the frame number each frame cycle normally maintains frame number synchronization between the two endpoints of the encryption/decryption function.

The transcoding unit **115** may support a variety of interfaces. The transcoding unit **115** may support the A-interface linking the transcoding unit **115** at the MSC **116**, and the T-interface linking the transcoding unit **115** to the base station controller **112**. The T-interface carries bearer voice data that is processed by the transcoding unit bearer functions and relayed on the A-interface to the MSC **116**, as well as A-interface signaling over SS7 links. Preferably, the transcoding unit **115** provides transparent pass-through of signaling between the base station controller **112** and MSC **116** over SS7 links and, optionally, X.25 or similar type links. The T-interface also carries signaling for OAM&P control of the transcoding unit **115**, and inband signaling between the transcoding unit **115** and the base station controller **112** for dynamic per-call control of the transcoding unit functions. Signaling exchanged between the transcoding unit **115** and the base station controller **112** is concentrated in a specific time slot (e.g., the first time slot of a time frame), and controlled through the level-2 link-access procedures for the D-channel (LAPD) protocol.

FIG. **9** is a high level diagram illustrating a preferred breakdown of bearer path functions performed at the wireless access communication unit **106**, the base station **109**, and the base station controller **112** and/or transcoding unit **115**. As shown in FIG. **9**, the wireless access communication unit bearer path functions **901** include voice encoding and decoding **911**, forward error correction (FEC) **912**, encryption and decryption **913**, and tone generation **914**. The base station bearer path functions **902** include backhaul framing **921** and channel multiplexing and demultiplexing **922**. The base station controller and transcoding unit bearer path functions **903** comprise voice encoding and decoding **931**, forward error correction (FEC) **932**, encryption and decryption **933**, backhaul framing **934**, and channel multiplexing and demultiplexing **935**. These functions have been mentioned previously in relation to the various components of the system, and are further described in various levels of detail elsewhere herein or in materials incorporated by reference herein.

As shown in FIG. **9**, the speech encoding/decoding, encryption/decryption and FEC functions performed in the wireless access communication unit **106** are mirrored in the based station controller **112** and/or transcoding unit **115**. The channel multiplexing/de-multiplexing and backhaul framing functions performed in the base station **109** are also mirrored by the base station controller **112** and/or transcoding unit **115**.

Referring again to FIG. **1**, the transcoding unit **115** is connected to the mobile switching center (MSC) **116**, which is connected to the PSTN **125**. The MSC **116** is a cellular switch that acts as an interface between the base station subsystem (BSS) and the PSTN **125**, and acts as the gateway to the long-distance network. The MSC **116** has telephone exchange capabilities including call setup, routing selection, switching between incoming and outgoing channels, control of communications, and release of connections. In addition, the MSC **116** performs its functions while taking into account mobility management aspects of the subscriber, including authentication, ciphering, radio resource management, and location register updating procedures. The MSC **116** also allows the wireless access communication unit **106** interworking to the PSTN **125**. The MSC **116** may be part of a digital multiplex system (DMS) "super-node" based switching system, capable of providing the switching functions in a cellular network. Also, the visitor location register (VLR) is preferably co-located and integrated with the MSC **116**.

The MSC **116** may support a variety of interfaces. The MSC **116** may support an A-interface providing linkage between the MSC **116** and the base station subsystem (BSS), particularly the base station controller **112** and the transcoding unit **115**, and a PSTN interface which is used for connecting the MSC **116** to the PSTN **125** across which voice and circuit traffic is transmitted. The MSC **116** also may support a mobile application part (MAP) interface, which is a CCS7 application permitting mobility information to be transferred among network level components. In addition, the MSC **116** may support a billing center interface, which is used for connecting the MSC **116** to a downstream processor for downloading of billing events; an operations management center (OMC) interface, which is used to administer the MSC **116** and visitor location register (VLR); and a service center interface, which is used for connecting the service center function responsible for relaying and store-and-forwarding short messages to mobile stations.

A variety of functions are preferably performed by the MSC **116**. For example, the MSC **116** preferably authenticates subscribers and, if accessible to the system, mobile

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stations. The MSC **116** interfaces to the PSTN **125**, and may interface to, for instance, public land mobile networks (PLMNs) or PCS-1900 networks. The MSC **116** also provides terrestrial channel allocation, and call control and signaling support. In addition, the MSC **116** may perform echo cancellation towards the PSTN **125**, handling and management of database information, charge recording, handling of subscriber registration and location management, and operation measurements.

The MSC **116** is connected to a home location register (HLR) and authentication center (AuC), collectively shown as an integrated unit HLR/AuC **123** in FIG. **1**. The HLR/AuC **123** may be built on a digital (e.g., DMS) super-node platform, and interconnect with various functional entities including the visitor location register, MSC, and mobile application part (MAP). The HLR component of the HLR/AuC **123** contains information about subscribers, services assigned to the subscribers, the status of such services, and any further information required to support the operation of the services when active. The HLR responds to requests from the MSC **116** and/or VLR to provide or update subscriber data. The HLR communicates with the VLR to download subscriber data and to obtain call routing information for the mobile stations in the region covered by the VLR.

The AuC component of the HLR/AuC **123** contains subscriber keys for use in authenticating attempts to access the network. The AuC component uses subscriber keys to generate authentication vectors, which are provided to the VLR via the HLR component. Further details regarding authentication, as noted, may be found in copending U.S. patent application Ser. No. 08/988,505, previously incorporated herein by reference.

In a mobile system, such as a PCS 1900 mobile system, the information held by the HLR component of the HLR/AuC **123** allows mobile stations to be addressed by means of a unique number, regardless of geographic location, thus allowing mobile stations to roam freely within and between networks. In a system providing fixed access wireless services in which a wireless access communication unit **106** and related components are utilized, the HLR component contains information similar to that maintained for mobile stations in a completely mobile-based system. The HLR component of the HLR/AuC **123** contains information regarding the subscribers interfacing with the wireless access communication unit **106**. As noted previously, the individual CPE trunks connected to the wireless access communication unit **106** (such as CPE trunks **602** shown in FIG. **6**) may appear as individual subscribers (i.e., "mobile stations") to the HLR and VLR. Hence, each CPE trunk connected to the wireless access communication unit **106** has its own (preferably unique) subscriber identity number. The subscriber identity number may, as noted previously, comprise an international mobile subscriber identity (IMSI), which is a unique, permanent identifier of a CPE trunk assigned at the time of manufacture of the CPE **105**, or may comprise a mobile subscriber ISDN (MSISDN) number, which would be one of the public PSTN numbers assigned to the CPE **105**.

Because the wireless network is likely to be configured to service individual mobile subscribers as well as being capable of servicing the wireless access communication unit **106**, the wireless access communication unit **106** may include functionality for keeping its non-mobile aspects transparent from the wireless network. For example, a mobile telephone subscriber may occasionally signal the wireless network to refresh the VLR on a regular basis. To keep the fixed wireless aspects of the system transparent to the wireless network, the wireless access communication unit **106** may periodically perform network-level registration using, for example, a GSM periodic registration mechanism, to keep the VLR entries for the "subscribers" alive. The wireless access communication unit **106** may also perform network-level registration every time it registers through a base station **109** in a location area different from that of the base station **109** to which it was previously connected. Further details regarding initial and periodic registration may be found in, e.g., copending U.S. Pat. application Ser. No. 08/987,872 filed concurrently herewith, and previously incorporated herein by reference.

Certain features relating to voice call establishment and maintenance will now be described in more detail, with reference to the interaction among various components of a communication system in which the wireless access communication unit **106** is deployed.

For "outgoing" voice call establishment initiated by the CPE **105**, the wireless access communication unit **106** handles acquisition of an over-the-air communication channel, mobility management connectivity, and call setup, and in addition is preferably capable of handling various error or exception conditions. When the wireless access communication unit **106** detects a trunk seizure by the CPE **105**, the wireless access communication unit **106** marks the CPE trunk as "busy" and issues a dial tone (assuming that it is able to communicate with a base station **109**). In parallel, the wireless access communication unit **106** initiates an over-the-air communication channel acquisition procedure. The dial tone is removed when the wireless access communication unit **106** detects the first dialed digit from the CPE **105**, or if it detects an on-hook from the CPE **105** prior to receiving any digits therefrom.

To facilitate initial acquisition of over-the-air communication channels, upon initial power-up the wireless access communication unit **106** preferably performs a thorough search of nearby base stations **109** to find a suitable base station **109**. The wireless access communication unit **106** establishes communication with the base station **109**, and receives a surrounding base station map from the current base station **109**. The surrounding base station map provides the wireless access communication unit **106** with a list of neighboring base stations **109** that are candidates for over-the-air communication. Using the surrounding base station map, the wireless access communication unit **106** builds up a base station selection table containing such things as signal quality information on the neighboring base stations **109**. The base station selection table is stored in non-volatile memory in the wireless access communication unit **106**. On subsequent power-ons, the wireless access communication unit **106** uses the existing base station selection table to speed up its base station acquisition.

On receiving a trigger from the CPE **105** to set up an outgoing call or perform a registration, the wireless access communication unit **106** attempts to acquire an over-the-air communication channel. In certain wireless systems the acquisition of an over-the-air communication channel is accomplished by interacting with a control channel of the wireless system. In certain types of TDMA systems, the channel acquisition process may entail acquiring a time slot in a time frame established by the base station **109**. Acquisition of a time slot may be carried out, for example, according to a handshake protocol described in more detail in U.S. Pat. No. 5,455,822, assigned to the assignee of the present invention, and hereby incorporated by reference as if set forth fully herein.

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If the wireless access communication unit **106** is unable to find an available over-the-air communication channel for communication with the base station **109**, its next action depends on whether or not there are other calls active or being set up through the wireless access communication unit **106**. If there are no other calls active or being set up through the wireless access communication unit **106**, then the wireless access communication unit **106** searches the surrounding area to find a base station **109** with which it can communicate. If a suitable base station **109** is found (based upon, for example, received signal quality and traffic availability), the wireless access communication unit **106** attempts to acquire an over-the-air communication channel on the new base station **109**. (For example, in one particular embodiment, the wireless access communication unit **106** may look for a general polling message sent within a time slot, wherein the general polling message indicates the availability of an over-the-air time slot for communication, as generally described in the above-referenced U.S. Pat. No. 5,455,822.) If the wireless access communication unit **106** fails to acquire an over-the-air communication channel, it may try again, or else search for a different base station **109**. The wireless access communication unit **106** continues with this process until it either acquires an over-the-air communication channel, or else a link establishment timeout period expires, indicating a failed attempt.

If there are other calls active or being set up through the wireless access communication unit **106** when a failed attempt to acquire another over-the-air communication channel with the current base station **109** occurs, then the wireless access communication unit **106** marks the channel acquisition attempt as failed. Alternatively, the wireless access communication unit **106** may attempt to set up the call with a different base station **109**, and thereby attempt maintain communication with two different base stations **109** (the one handling the currently active calls and the one handling the newest call) simultaneously.

If the over-the-air communication channel acquisition attempt has failed, the wireless access communication unit **106** issues a "reorder" tone on the CPE trunk, and marks the over-the-air link status as congested. If the wireless access communication unit **106** has a ground-start trunk interface with the CPE **105**, then the wireless access communication unit **106** busies its idle CPE trunks by seizing them (i.e., applying tip to ground on each CPE trunk **602**). So long as the congested condition is in effect, the CPE **105** attempts to route the calls that would otherwise be directed to the wireless access communication unit **106** to the PSTN **125** (assuming that the CPE **105** has call routing capability). While in the "congested" state, the wireless access communication unit **106** continues to track the over-the-air channel availability on the current base station **109**. Should the congested condition clear (e.g., it is able to see general polling messages from the base station **109**, or otherwise receive information from the base station **109** indicating available communication channels), the wireless access communication unit **106** then marks the over-the-air link status as "uncongested." If the wireless access communication unit **106** has a ground-start trunk interface with the CPE **105**, then the wireless access communication unit **106** un-busies any CPE trunks by releasing them (i.e., removing tip from ground).

If acquisition of an over-the-air communication channel is successful, then the wireless access communication unit **106** proceeds with digit transmission and analysis. On detecting the first dialed digit, the wireless access communication unit **106** removes the dial tone and initiates a digit analysis procedure. In a preferred embodiment, digits are relayed from the wireless access communication unit **106** as they are received after the over-the-air communication channel has been established, and digit analysis is performed at the base station **109**. The base station **109** stores the digits and analyzes them, determining the type of call and the end of the dialing sequence.

In an illustrative embodiment, the base station **109** analyzes the digits as follows. If the base station **109** detects the digit pattern "X11," where "X" is a "4" or a "9", it will consider dialing to be complete. If the digit sequence is "911," the base station **109** marks the call type as an emergency call. Any other type of call is marked as a normal call. If the first three digits are not "411" or "911," then the base station **109** continues to receive digits, and uses a dialing-complete timeout period (of, e.g., four seconds) to detect the end of dialing. To implement the dialing-complete timeout period, a dialing timer is activated when the first digit is received by the base station **109**, and is reset each time a new digit is received. When the dialing timer expires, the base station **109** considers dialing to be complete.

On determining that the dialing sequence is complete, the base station **109** issues a trigger to the wireless access communication unit **106** to continue with call establishment, including mobility management connection establishment and call setup. This trigger also indicates the type of call (i.e., normal versus emergency).

Several types of exceptions or errors may occur in the attempt to establish a communication path from the user (i.e., telephone station **102**) to the base station **109**. For example, if the wireless access communication unit **106** is unable to communicate with the base station **109**, then the wireless access communication unit **106** will not generate a dial tone. Instead, it will issue a reorder tone to the user via the CPE **105**. If no digit is received by the wireless access communication unit **106** for a predetermined timeout period (e.g., 16 seconds) after the trunk seizure is recognized by the wireless access communication unit **106**, then it applies permanent signal treatment on the trunk (i.e., treats it as an extended off-hook situation), as further described below. If the dialing from the user is incomplete, or if the dialed number is invalid, then the MSC **116** takes appropriate action. In such situations, the base station **109** generally detects end-of-dialing and triggers the wireless access communication unit **106** to set up the call. The incomplete or invalid digit sequence is then filled into a DTAP Setup message by the base station **109** and sent to the MSC **116**. The digit analysis performed at the MSC **116** detects the exception condition, causing the MSC **116** to return a DTAP Release Complete message to the wireless access communication unit **106**, indicating that the dialed number is invalid.

If the wireless access communication unit **106** should lose communication with its current base station **109**, or if the quality of one or more over-the-air communication links has dropped below an acceptable minimum (based on, e.g., high bit error rate, low signal strength, and the like), the wireless access communication unit **106** starts a base station acquisition procedure to locate a base station **109** that it can communicate with satisfactorily. For a ground-start trunk interface between the wireless access communication unit **106** and the CPE **105**, the wireless access communication unit **106** "busies" its CPE trunks by seizing them—i.e. by applying tip to ground on each CPE trunk **602**. On completing base station re-acquisition (either by re-establishing communication with the current base station **109** or finding a strong enough RF link with a different base station), the

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wireless access communication unit **106** un-busies each of the CPE trunks that were busied out when communication with the base station **109** was lost or interrupted.

In another aspect of the invention, each CPE trunk supported by the wireless access communication unit **106** represents a logical subscriber to the network, even though the multiple CPE trunks are physically connected to the wireless access communication unit **106**. Thus, for example, where four CPE trunks **602** are connected to the wireless access communication unit **106**, four unique subscriber identifiers are allocated. The use of different logical subscriber identifiers for each CPE trunk **602** permits multiple calls to be handled by the wireless access communication unit **106** across one or more wireless links to the base station **109**. In a particular embodiment, each CPE trunk **602** is identified with its own unique international mobile subscriber identity (IMSI) number and mobile station ISDN (MSISDN) number for addressing. When the wireless access communication unit **106** initiates "mobility management" and call control procedures on behalf of one of the connected CPE trunks, it uses the IMSI assigned to that CPE trunk.

To the network side of the system (i.e., the base station **109**, base station controller **112**, MSC **116**, etc.), each logical subscriber associated with the wireless access communication unit **106** is seen as a separate user, much like the separate mobile subscribers that can also communicate wirelessly with the base station **109**. The base station **109** generally need not know that a group of different IMSIs belongs to a single entity (i.e., the wireless access communication unit **106**). The IMSIs are preferably held on one or more subscriber interface module (SIM) **606** chips, programmed at the factory. Each SIM **606** chip, once placed in the wireless access communication unit **106**, belongs to a specific CPE trunk. The IMSI is used, as described elsewhere herein, for such things as registration, authentication, and network access.

For each IMSI stored in the wireless access communication unit **106** there preferably is a corresponding MSISDN stored in the HLR component of the HLR/AuC **123**. The MSISDN number may be the equivalent of the NANP number converted into an MSISDN number—i.e., a number in the format of 1+NPA+NXX+XXXX. The MSISDN number is used for such things as call origination and billing generation. The MSISDN number may be one of the public PSTN numbers assigned to the CPE **105**; therefore, the MSISDN number may be assigned to the CPE **105** from the PSTN **125**.

The wireless access communication unit **106** may be assigned an identifying serial number in the form of an International Mobile Equipment Identity (IMEI) number. The IMEI number may be assigned at the factory, and each wireless access communication unit **106** is preferably associated with a unique IMEI number. If an Equipment Identity Register (EIR) element is used within the network, it will contain the IMEI number of each wireless access communication unit **106** in the system. Alarms generated by the wireless access communication unit **106** may use the IMEI number for identification purposes.

As previously mentioned herein, the invention provides in one aspect signaling techniques and protocols for facilitating communication in a system having a wireless trunk. Signaling information is transported across one or more of the various interfaces of the communication system **101**, so as to allow communication between the CPE **105** and the PSTN **125** to take place utilizing the capabilities of the wireless access communication unit **106**. In a preferred embodiment, the communication system **801** incorporates aspects of the IS-661 communication protocol (or a modified version of the IS-661 protocol) and the GSM communication protocol, thereby employing a "hybrid" protocol.

Various aspects of the IS-661 protocol may be summarized as follows. According to the IS-661 protocol, over-the-air communication between a base station **109** and mobile stations or other user stations is carried out using frequency division duplexing (FDD) wherein the base station **109** transmits over a base station frequency band, and the mobile stations or other user stations transmit over a mobile/user station frequency band. Transmissions are distinguished according to time slots, with a TDMA time frame on each of the base station frequency band and mobile/user station frequency band comprising 32 time slots, each 625 microseconds in length, resulting in a TDMA time frame duration of 20 milliseconds. (In some variations, however, only 16 duplex time slots are used.) A preferred frequency of operation is 1850 to 1990 MHz, with a synthesizer tuning step size of 100 kHz. Communication is carried out using spread spectrum communication, with a 1.6 MHz RF channel spacing. Spread spectrum modulation may be MSK or OQPSK with pulse shaping implemented using a root raised cosine method. The spread spectrum chipping rate is preferably 1.25 Megachips (Mcps) on each of two channels, an I channel and a Q channel. The system may provide for antenna diversity, and may also provide for power control of the mobile stations or other user stations in predefined steps (of, e.g., 3 dB).

Further details regarding the particulars of the IS-661 protocol utilized in a preferred embodiment are described elsewhere herein, or may found in the OMNI_Notes_RMT Protocols Rev. 02.03D filed as Technical Appendix A herewith.

The different interfaces of the communication system may employ different protocols depending in part upon where in the chain of the communication path the interface appears. FIG. **10** is a diagram showing interfaces between different components of a communication system **801** according to a preferred embodiment of the present invention. Some of these interfaces have also been generally described previously with respect to the preferred base station **501** shown in FIG. **5**. The different interfaces shown in FIG. **10** include an over-the-air interface or "O-interface" **560** between a wireless access communication unit **106** and the base station **109**, an internal interface or "I-interface" **561** internal to the base station **109** (i.e., between the OTA manager **502** and the line card manager **503** of the preferred base station **501**, as shown in FIG. **5**), and a network interface or "N-interface" **562** between the base station **109** and the base station controller **112**. The base station controller **112** communicates with the MSC **116** over a standard interface such as the GSM A-interface **571**.

In a preferred embodiment, in accordance with the embodiment of the invention shown in FIG. **1**, a transcoding unit **115** is interposed between the base station controller **112** and the MSC **116**. In this embodiment, an additional interface designated the "T-interface" is provided between the base station controller **112** and the transcoding unit **115**, and the transcoding unit **115** communicates with the MSC **116** over a standard interface such as the GSM A-interface **571**.

Each of the communication interfaces shown in FIG. **10** will now be described in more detail, starting with the "O-interface" **560** between the wireless access communication unit **106** and the base station **109**. The "O-interface" **560**

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comprises one or more wireless, over-the-air communication channels, each channel preferably (but not necessarily) including a forward communication link and a reverse communication link to support full duplex communication. The over-the-air communication channel(s) of the O-interface **560** may be implemented according to any of a variety of different multiple-access communication protocols, including protocols utilizing time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), or various combinations thereof. The O-interface **560** may include, in some alternative embodiments, wireless broadcast channels from the base station **109** that are used, for example, for transmitting control traffic and signaling information. In other embodiments dedicated broadcast control channels are not used.

In a preferred embodiment, the base station **109** is part of a cellular network that employs aspects of FDMA, TDMA and CDMA for cell isolation. In an exemplary embodiment, users are isolated, and multiple access is achieved, through TDMA. Frequency division duplexing (FDD) is utilized to permit 16 full duplex users to share a common RF radio frequency. Adjacent cells in the cellular network are assigned one of nine frequency channels and use a code reuse pattern of seven to achieve isolation between the cells. Direct sequence spread spectrum transmissions are used by the base stations **109** and the users within a cell, including the wireless access communication unit **106**. Spread spectrum communication reduces interference between cells as well as with respect to other systems (e.g., PCS systems) operating within the same proximity. Cells in adjacent clusters use a variety of interference rejection techniques, including orthogonal or near orthogonal spreading codes, transmit power control, directional antennas and time slot interchange (TSI).

One possible communication protocol that may be used for communicating across the O-interface **560** in one embodiment of the present invention is depicted in FIG. **25**. The protocol depicted in FIG. **25** makes use of time division multiple access (TDMA) and spread spectrum techniques. As shown in FIG. **25**, a polling loop **1380** ("major frame") comprises a plurality of time slots **1381** ("minor frames"). Each minor frame **1381** comprises communication between a base station **109** (e.g., cellular station) and a user station (e.g., mobile user) in time division duplex—that is, the base station **109** transmits to a user station and the user station transmits back to the base station **109** within the same minor frame **1381**.

More specifically, as shown in an exploded view of a portion of the polling loop **1380** in FIG. **25**, a minor frame **1381** comprises a mobile or user transmission **1382** preceding a base transmission **1383**. The minor frame **1381** also comprises a variable radio delay gap **1384** preceding the user transmission **1382**, followed by a turn-around gap **1388** and a guard time gap **1389**. After gap **1389** is the base transmission **1383**, which is followed by another turn-around gap **1393**. The user transmission **1382** comprises a preamble **1385**, a preamble sounding gap **1386**, and a user message interval **1387**. The base transmission comprises a preamble **1390**, a preamble sounding gap **1391**, and a base message interval **1392**.

Another communication protocol that may be used for communication across the O-interface **560** is depicted in FIG. **26**. The protocol depicted in FIG. **26** uses aspects of both FDMA (in the sense that transmissions are distinguished by different frequency allocations) and TDMA (in the sense that transmissions are distinguished by separate time allocations). As shown in FIG. **26**, one frequency band **1510** is allocated to a base station **109** for base-to-user transmissions, and another frequency band **1511** is allocated to user stations (e.g., handsets, or other wireless units) for user-to-base transmissions. A repeating major time frame (or "polling loop") **1501** is defined for communication over each frequency band **1510**, **1511**. A plurality (e.g., sixteen) of base time slots **1502** and user time slots **1503** are defined within the repeating major time frame **1501**, with the user time slots **1503** preferably lagging behind the base time slots **1502** by an amount of time. In a preferred embodiment, in which sixteen base time slots **1502** and sixteen user time slots **1503** are defined in each major time frame **1501**, the time lag **1505** between the first base time slot **1502** and first user time slot **1503** is a preset amount of time corresponding to a number of time slots, such as eight time slots, and is therefore referred to as a "slot offset." This time lag or slot offset **1505** allows user stations time to receive transmissions over the base frequency band **1510** in the assigned base time slot **1502**, process the base-to-user transmissions, perform a transmit/receive frequency switch, and transmit a reverse link transmission in the corresponding user time slot **1503**, without having to wait an entire time frame duration to transmit a reverse link transmission. The slot offset **1505** can comprise an amount of time other than eight time slots, or the major time frame **1501** can be defined such that there is no slot offset **1505** at all.

Alternatively, instead of having a fixed time lag or slot offset **1505**, base time slots **1502** and user time slots **1503** can be assigned independently, with the spacing between a base time slot **1502** and a corresponding user time slot **1503** (i.e., a duplex pairing) being selected dynamically based upon, for example, the type of user.

In a preferred embodiment, the user time slot(s) **1503** and base time slot(s) **1502** assigned to the wireless access communication unit **106** are offset by an amount of time sufficient to allow transmit/receive frequency switching of the radio transceiver at the wireless access communication unit **106**. In one embodiment, the wireless access communication unit **106** requires approximately 625 microseconds to perform a transmit/receive frequency switch, which corresponds to half of a time slot duration if the time slots **1502**, **1503** are each 1.35 milliseconds in length. An offset of eight slots between the base time slot **1502** and corresponding user time slot **1503** so as to form a "virtual" time slot is presently preferred. A slot offset of eight is deemed, within the context of the preferred embodiment, sufficient to accommodate four trunks per wireless access communication unit **106** in the available over-the-air slot space, while reducing the potential number of transmit/receive frequency switches by the wireless access communication unit **106**.

In accordance with one embodiment, the wireless access communication unit **106** transmits to the base station **109**, at the time of negotiating a slot allocation with the base station **109**, a slot assignment map indicating which over-the-air slots are already assigned to calls on the wireless access communication unit **106**. The base station **109** uses the slot assignment map information to pick a base time slot **1502** and user time slot **1503** from the pool of available time slots **1502**, **1503**. The base station **109** makes this selection based upon, for example, transmit/receive switching time constraints of the wireless access communication unit **106**.

In one aspect of a preferred communication protocol, a single base time slot **1502** and a single user time slot **1503** collectively comprise a duplex communication channel. In a preferred embodiment, the time frame **1501** of the protocol described with reference to FIG. **26** supports sixteen base

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time slots **1502** and sixteen corresponding user time slots **1503**, for a total of sixteen possible duplex communication channels. In a preferred embodiment, each base time slot **1502** and user time slot **1503** is 1.35 milliseconds in duration, and each time slot permits 9.6 kilobits/second for the transmission of encoded speech or other data.

The number of wireless access communication units **106** supportable by a single base station **109** is generally a function of the number of communication channels available at the base station **109** and the number of communication channels (i.e., CPE trunks) required by the wireless access communication unit **106**. For example, where sixteen communication channels are available at the base station **109**, and where each wireless access communication unit **106** has four CPE trunks **602**, the base station **109** can support four wireless access communication units **106**, each operating at maximum capacity, at a given time. However, where it is expected that the wireless access communication units **106** will operate at less than maximum capacity for periods of time, and based on blocking requirements and expected subscriber loads, more than four wireless access communication units **106** could be assigned to a single base station **109**, with the wireless access communication units **106** using the base station **109** as a shared resource. In addition, the base station **109** may communicate with other wireless users, such as mobile handsets or other wireless devices, simultaneously with its communication with one or more wireless access communication units **106**.

Communication channels are preferably assigned to the wireless access communication unit **106** on a demand basis, although they may, in certain embodiments, be pre-allocated as well. An advantage of dynamic assignment of over-the-air communication channels is that more users can be supported. For the protocol shown in FIG. **26**, over-the-air communication channels are preferably assigned based on requests from the wireless access communication unit **106** to the base station **109**. The assignment of over-the-air communication channels is carried out in the same fashion for mobile users (if any) that also communicate with the base station **109**—i.e., according to the cellular communication protocol for the network of which the base station **109** is a part. For example, over-the-air communication channels may be assigned with the assistance of a dedicated control channel. Over-the-air communication channels may also be assigned according to techniques similar to those described in, for example, U.S. patent 5,689,502, hereby incorporated by reference as if set forth fully herein. Any other suitable mechanism for allocating or assigning over-the-air communication channels may also be used.

While the O-interface **560** generally involves the direct wireless interface between the wireless access communication unit **106** and the base station **109**, several other interfaces, as depicted in more detail in FIG. **10**, are involved in exchanging information with the PSTN **125**. The next interface in progression towards the PSTN **125** is the I-interface **561**. The I-interface **561** is internal to the base station **109**, and generally provides for, among other things, the translation of the radio messages to a format suitable for backhaul transmission to the network, and vice versa. Details of a preferred I-interface **561** may be found in, e.g., U.S. Pat. 5,689,502, hereby incorporated by reference as if set forth fully herein. Further details of the I-interface **561** are also discussed herein with respect to FIG. **5**.

The next interface in the progression from the wireless access communication unit **106** towards the PSTN **125**, as shown in FIG. **10**, is the N-interface **562**, which connects the base station **109** to the base station controller **112**. The N-interface **562** comprises both traffic and signaling communication channels, as described further herein. At the physical layer, the N-interface **562** uses a fractional T1 service as the transport mechanism. Each fractional T1 link supports transfer rates from 64 kilobits/second up to 1.536 megabits/second. Each time slot on the T1 link supports up to four 16 kilobit/second bearer channels.

The traffic channels of the N-interface **562** include non-aggregated 16 kilobit/second channels for carrying data (e.g., speech data) for one radio traffic channel (i.e., one over-the-air communication channel). Up to four such traffic channels can be multiplexed into one 64 kilobits/second T1 time slot. A single signaling channel is provided for each base station **109** for carrying signaling and OAM&P information, at a rate of 64 kilobits/second. The signaling traffic includes control information pertaining to the link between the base station **109** and the base station controller **112**, as well as signaling traffic relayed between the wireless access communication unit **106** and the MSC **116**.

To manage signaling and operations or administrative messaging over the N-interface **562**, LAPD terminal endpoint identifiers (TEIs) are used for the transfer of signaling and OAM&P information between the base station controller **112** and a base station **109**, as well as control information between a local management terminal (if provided) and the base station **109**. TEIs are preferably assigned to the base common function (see FIG. **7**, described below) and the transceivers which transmit and receive messages over the N-interface **562**. A base common function TEI is permanently assigned to a T1 time slot on the N-interface **562**, and is derived from the T1 time slot number. Transceiver TEIs are semi-permanent and are established from configuration parameters. Different functional entities within the base common function and the backhaul transceivers are addressed using service access point identifiers (SAPIs). In a particular embodiment, a single backhaul transceiver is supported by the base station **109**, and hence in such an embodiment only one transceiver TEI is used.

FIG. **7** shows in more detail the interface signaling structures for the N-interface **562** used in conjunction with a preferred embodiment of the invention. As shown in FIG. **7**, a base station controller (BSC) **702** is connected to a base station (OBTS) **703** over a plurality of logical links **711** through **715**, all of which are, from a physical standpoint, multiplexed onto a single digital timeslot channel (or DS**0**) and transmitted using pulse code modulation (PCM). The base station **703** shown in FIG. **7** comprises two transceivers **706**, **707** (designated "TRX1" and "TRX2," respectively), which are identified by terminal endpoint identifiers TEI B and TEI C, respectively, and a base common function (BCF) **705**, which is identified by terminal endpoint identifier TEI A.

Logical links **711** through **715** may be categorized according to service access provider identifier (SAPI) type. For example, in the embodiment shown in FIG. **7**, a SAPI type of "62" indicates OAM&P signaling, while a SAPI type of "0" indicates traffic signaling. As illustrated by the interface signaling structure shown in FIG. **7**, one OAM&P SAPI logical link **712** and one traffic signaling logical link **713** are logically associated with one transceiver **706**, and another OAM&P SAPI logical link **714** and traffic signaling logical link **715** are associated with the other transceiver **707**. A third OAM&P logical link **711** is logically associated with the base common function **705**.

Signaling messages for traffic control are transmitted on two of the logical links **713** and **715**, one of each connected

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to transceivers **706** and **707**. Signaling messages carried by logical links **713** and **715** for interactions between the base station **703** and base station controller **702** relate to functions such as, for example, backhaul and radio resource management, and mobility management. Signaling messages carried by channels **713** and **715** also relate to end-to-end call control and mobility management signaling between the wireless access communication unit **106** and the MSC **116**, and are encapsulated within transport notes. In addition, observation counters and operation measurements sent by the base station **703** to the base station controller **702**, and encapsulated within transport notes, can be conveyed across logical links **713** and **715**.

Messaging related to management functions (such as OAM&P) is carried on logical links **711**, **712** and **714**, to the base common function **705** and transceivers **706** and **707**, respectively. The OAM&P messaging provides for management of the base station **703** by the base station controller **703**.

In a preferred embodiment, the base station controller **112** is connected to a transcoding unit **115** over an T-interface, which is shown in FIG. **1** but not explicitly shown in FIG. **10**. The T-interface links the base station controller **112** to the transcoding unit **115** over a T1 connection, which carries a variety of different links, including bearer voice channel links and signaling links. The T-interface carries a plurality of **16** kilobits/second bearer voice channels containing coded, encrypted voice and FEC information, along with inband signaling information between the base station **109** and the transcoding unit **115** (i.e., the endpoints of the encryption/decryption algorithms). In one embodiment, up to four such bearer voice channels can be multiplexed onto one DS**0** timeslot. The bearer voice channels are processed for transcoding and rate adaptation functionality by the transcoding unit **115**, which formats the bearer voice channel data into 64 kilobits/second pulse-code modulated (PCM) voice data for relay to the MSC **116**.

In addition to bearer data, the T-interface also carries one or more signaling links. For example, the T-interface carries signaling links for OAM&P control of the transcoding unit **115** by the base station controller **112**, using a standard LAPD data link. The T-interface also carries SS**7** signaling links between the base station controller **112** and the MSC **116**, each using one T1 DS**0** timeslot. The signaling information on these links is relayed transparently between the base station controller **112** and the MSC **116** through the transcoding unit **115**. The T-interface may also optionally carry the communication link between the base station **109** and the operations management center (OMC) **120**.

The transcoding unit **115** (if provided) is connected to the MSC **116** over a standard interface, such as the GSM A-interface. Alternatively, the functionality of the transcoding unit **115** may be incorporated in the base station controller **112**, which then would connect to the MSC **116** over a standard interface such as the GSM A-interface. The A-interface is depicted in FIG. **1**, and is also denoted in FIG. **7** by reference numeral **571**. Details of the GSM A-interface are described in, for example, "Mobile Switching Center (MSC) to Base Station Subsystem (BSS) Interface; Layer **3** Specification," GSM Recommendation 08.08. Preferably, some modifications are made to the standard GSM A-interface to support the features and functionality of the preferred embodiment or embodiments described herein. Such modifications may include, for example, using a T1 line as the physical interface to carry both traffic and signaling, and using μ-law coding in certain geographical regions (such as North America).

Signaling links for the A-interface, in general, logically run between the base station controller **112** and the MSC **116**, whereas the bearer links span between the transcoding unit **115** and the MSC **116**. The transcoding unit **115**, as noted, processes the 16 kilobits/second bearer links received over the T-interface, and generates 64 kilobits/second pulse-code modulation links towards the MSC **116**. The A-interface signaling channels carry signaling connection control part (SCCP) logical signaling links. An SCCP link is maintained between the base station controller **112** and the MSC **116** for each active CPE trunk (or "logical mobile station") of the wireless access communication unit **106** that is communicating with the PSTN **125**. Signaling information carried over the A-interface includes SS**7** signaling between the base station controller **112** and the MSC **116** for management of the link, A-interface radio resource management signaling, A-interface mobility management signaling, call control signaling between the wireless access communication unit **106** and the MSC **116** relayed through the base station controller **112**, and, optionally, OAM&P signaling between the base station controller **112** and the OMC **120**. The A-interface signaling traffic passes through the transcoding unit **115** (if provided), and the transcoding unit **115**, as noted, relays the signaling information transparently between the base station controller **112** and the MSC **116**.

As noted previously herein, both GSM and non-GSM aspects of signaling are utilized in a preferred communication system **101** in accordance with the present invention. In a preferred embodiment, aspects of GSM signaling and messaging are used within the communication system **101** such that the interworkings of the physical protocol are essentially transparent at the network level. In this embodiment, a non-GSM physical layer is employed, while communication with the MSC **116** is packaged using a GSM signaling format so that the non-GSM aspects of the wireless system are transparent to the network. Details of the various interfaces used in a preferred system have been described above, while details of signaling and protocols carried out within the communication system **101** are described in more detail below. While the signaling and protocols are described with reference to the specific interfaces shown in FIGS. **1**, **7** and **10**, aspects of the signaling and protocols may also be employed using other interface configurations as well.

FIG. **8** is a diagram showing a protocol architecture for one particular embodiment of the preferred communication system **101**, and further depicts a preferred relationship of connections among the wireless access communication unit **106**, base station **109**, base station controller **112**, and MSC **116** across the O-interface **560**, N-interface **562** and A-interface **571**. In the protocol architecture shown in FIG. **8**, "CM" relates to connection management, "MM" relates to mobility management, "OTA" relates to the over-the-air protocol, "LAPD" relates to link access protocol for the D channel, "IWF" relates to an interworking function, "Ph L" relates to the physical layer, "BSSMAP" relates to the base station subsystem management application part, "SCCP" relates to SS**7** signaling connection control part, "MTP" relates to message transfer part (MTP Layers **2** and **3**), "OAM" relates to operations, maintenance and administration, "NTS-MM" relates to N-Notes mobility management, and "NTS-RR" relates to N-Notes radio resource management.

For most of the physical radio functions, a preferred embodiment of the communication system utilizes the protocol architecture for the IS-661 mobility system. For higher level functionality, a preferred embodiment of the communication system uses aspects of GSM, as described in more detail hereinafter.

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The call control protocol is the GSM direction transfer application part (DTAP) call control entity, shown as the GSM-CM layer in FIG. **8**. This GSM DTAP call control entity (i.e., GSM-CM layer) supports a variety of features, including (1) the establishment, maintenance and release of normal outgoing voice calls (i.e., originating from the CPE **105**) between the wireless access communication unit **106** and the MSC **116**; (2) the establishment, maintenance and release of emergency (i.e., "911") outgoing voice calls between the wireless access communication unit **106** and the MSC **116**; and (3) the signaling of DTMF tones from the CPE **105** in the network direction during active calls. Preferably, transparent digit transmission is provided between the wireless access communication unit **106** and the base station **109**, since digit analysis is preferably carried out at the base station **109**. Further, the system also preferably provides transport capability via control transfer (CT-TRA) O-Notes for DTAP protocol messages.

A GSM DTAP mobility management entity, shown as the GSM-MM layer in FIG. **8**, is used end-to-end (between the wireless access communication unit **106** and the MSC **116**) to run various mobility management procedures, including authentication and subscriber identification. Other mobility management procedures are supported on the O-interface **560** and the N-interface **562** as part of the protocols utilizing O-Notes and N-Notes, and are shown as the OTA-MM entity and NTS-MM entity in FIG. **8**. These other mobility management procedures include location updating or network-level registration (both normal and periodic), IMSI detach or de-registration, temporary mobile subscriber identity (TMSI) reallocation, and mobility management connection establishment (for both normal and emergency calls). These mobility management procedures undergo interworking within the base station **109** and the base station controller **112**, and the base station controller **112** converts these into the corresponding GSM mobility management procedures over the A-interface **571**. In addition, base-level registration (both normal and periodic) between the wireless access communication unit **106** and the base station **109** is supported according to the O-Notes mobility management procedure.

The GSM-CM and GSM-MM protocol runs end-to-end between the wireless access communication unit **106** and the MSC **116**, and the protocol messages are relayed transparently through the base station **109** and the base station controller **112**. The protocol messages may be encapsulated within transport O-Notes (CT-TRA) messages across the O-interface **560**, transport N-Notes messages across the N-interface **562** using the LAPD signaling link between the base station **109** and base station controller **112**, and BSSMAP messages over the A-interface **571** using the SCCP signaling link.

The over-the-air mobility management procedures are interworked in the base station **109** with N-Notes mobility management procedures, shown as the NTS-MM Layer in FIG. **8**. The NTS-MM procedures run over the LAPD signaling link of the N-interface **562**, and are interworked in the base station controller **112** with corresponding DTAP mobility management (GSM-MM) procedures on the A-interface **571**. The GSM-MM protocol therefore runs partly end-to-end between the wireless access communication unit **106** and the MSC **116**, and partly between the base station controller **112** and the MSC **116**.

Over-the-air radio resource management functions are provided by an OTA radio resource (OTA-RR) management protocol entity shown in FIG. **8**. Such radio resource management functions include link acquisition, lost link recovery, bearer message ciphering, over-the-air slot negotiation and time slot interchange (in a TDMA system), digit transmission and analysis, assignment and mode change, link release (whether initiated by the network or wireless access communication unit **106**), base assist information, and surrounding base table information. On the O-interface **560**, the radio resource management is carried out as part of the O-Notes protocol by the OTA-RR entity.

The O-Notes protocol over the O-interface **560** includes link layer functions to manage the wireless communication channels (i.e., wireless communication links). These link layer management functions include ARQ, cyclic redundancy check (CRC), segmentation and de-segmentation, power control, and the like.

The elements of the radio resource functionality requiring interaction with the base station controller **112** and the MSC **116** are interworked by the base station **109** with the radio resource functionality within the N-Notes protocol on the N-interface **562**, indicated by the NTS-RR entity in FIG. **8**. The base station controller **112** in turn interworks the radio resource functionality with the BSSMAP layer functions on the A-interface **571**. Radio resource management procedures such as channel assignment, channel release, and the like are initiated through BSSMAP procedures by the MSC **116**, and the base station controller **112** translates these into NTS-RR protocol procedures on the N-interface **562**.

Over the N-interface **562**, the NTS-RR protocol procedures for radio resource management include ciphering, assignment and mode change, and link release. In addition to radio resource functions, the functionality of the NTS-RR entity includes procedures to manage the allocation and de-allocation of bearer channels on the backhaul link(s) of the N-interface **562**.

On the N-interface **562**, the signaling link is based on the LAPD protocol. Over the A-interface, the BSSMAP messages are carried over SCCP connections. The SCCP and MTP layers are used to provide a robust signaling link between the base station controller **112** and the MSC **116**.

Various BSSMAP procedures are provided on the A-interface **571** for supporting the functionality of the wireless access communication unit **106**. These BSSMAP procedures include, for example, assignment, blocking, reset, release, cipher mode control, and initial message.

Because the wireless access communication unit **106** may, if desired, be deployed in a fixed manner, certain mobility features need not be supported. For example, the wireless access communication unit **106** need not be required to support in-call handover to a different base station, broadcast channels, asymmetric channels, sub-rate channels, aggregated channels, multiple mode traffic, ciphering of signaling messages, or an over-the-air D-channel. Also, the wireless access communication unit **106** need not support incoming call paging, SMS call invocation, or call related supplementary services. Eliminating these features makes the wireless access communication unit **106** easier to implement, and simplifies support features required from the base station subsystem and other network-side components.

Mobility management connection establishment for normal calls is initiated by the mobility management entity (i.e., GSM-MM entity shown in FIG. **8**) of the wireless access communication unit **106**. To do so, the mobility management entity sends a Connection Management (CM) Service Request message to the MSC **116**, with the Service Type field indicating a normal call. The MSC **116** responds by sending a CM Service Accept message. Upon receiving a CM Service Accept message from the MSC **116**, the wireless

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access communication unit **106** continues with normal call set-up, as further described herein and/or in related applications incorporated by reference elsewhere herein.

For normal calls, the mobility management connection establishment procedure may encompass an authentication procedure. Such a procedure may be based on the DTAP mobility management signaling for authentication, and may run end-to-end between the MSC **116** and the wireless access communication unit **106**.

For emergency (i.e., "911") calls, the mobility management entity (i.e., GSM-MM entity shown in FIG. **8**) of the wireless access communication unit **106** initiates a mobility management connection establishment procedure by sending a CM Service Request message, with the CM Service Type field indicating an emergency call, to the MSC **116**. In response, the MSC **116** transmits a CM Service Accept message to the wireless access communication unit **106**. Upon receiving the CM Service Accept message from the MSC **116**, the wireless access communication unit **106** continues with emergency call setup. For emergency calls, the network need not invoke an authentication procedure.

If the service request is rejected by the MSC **116**, or if a service request time-out expires, the wireless access communication unit **106** may issue a reorder tone to the CPE **105**, and abort the call establishment procedure.

Although the wireless access communication unit **106** preferably utilizes a mobility management connection establishment procedure in the establishment of a call connection, the CPE trunks typically do not constitute mobile components of the system. The communication system **101** adapts techniques utilized in a mobile communication system for facilitating setup and maintenance of a wireless trunk **108** through the wireless access communication unit **106**, as generally described herein. Using aspects of a mobile communication system in the communication system **101** which includes the wireless access communication unit **106** has the advantage of allowing existing mobile communication system infrastructures to support a wireless trunk in accordance with the present invention, without requiring a separate base station subsystem or other dedicated wireless path to the PSTN **125** to be constructed.

After the mobility management connection establishment procedure has been completed, the wireless access communication unit **106** exchanges DTAP signaling with the MSC **116** to set up an outgoing call. The primary difference between normal and emergency call setup procedures is in the way the call is initiated. For a normal call, the wireless access communication unit **106** sends a DTAP Setup message to the base station **109** with the Called Address field empty. The base station **109** fills in the Called Address field of the Setup message with the digits stored earlier as part of the digit analysis procedure, before relaying the Setup message to the MSC **116** across the base station controller **112**. For an emergency call, the wireless access communication unit **106** sends a DTAP Emergency Setup message to the MSC **116**. The DTAP Emergency Setup message is relayed transparently through the base station **109** and the base station controller **112**. The MSC **116** returns a DTAP Call Proceeding message to indicate acceptance of the call request.

If the wireless access communication unit **106** receives a DTAP Progress message from the MSC **116** indicating PSTN interworking, the wireless access communication unit **106** connects its speech path between the CPE trunk and the wireless communication link (e.g., an over-the-air time slot, if the wireless communication channel is a TDMA time slot). The wireless access communication unit **106** then expects the call progress tones (busy/ringback) to arrive from the network (i.e., PSTN **125**) inband. As the call progresses, the wireless access communication unit **106** translates the call progress signals received from the MSC **116** to appropriate tones or signals on the CPE trunk.

If the wireless access communication unit **106** receives a DTAP Alerting message from the MSC **116**, the wireless access communication unit **106** generates a ringback tone towards the CPE **105**. The tone is removed under certain conditions, including: (1) a DTAP Connect message is received from the MSC **116**, indicating that the called user has answered the call; (2) the call is cleared from the network end, with a DTAP Disconnect or Release Complete message; (3) the call is released via a link level (over-the-air) release; (4) timer expiry occurs at the wireless access communication unit **106**; or (5) the wireless access communication unit **106** detects an on-hook indication from the CPE **105**.

If the wireless access communication unit **106** receives a DTAP Disconnect or Release Complete message, indicating that the called party is busy, the action by the wireless access communication unit **106** depends on whether or not there is PSTN interworking. If the wireless access communication unit **106** has received no indication of PSTN interworking, the wireless access communication unit **106** issues a busy tone to the CPE **105** and starts a busy tone timer. The busy tone is removed by the wireless access communication unit **106** if it detects an on-hook indication from the CPE **105**, or upon expiration of busy tone timeout period timed by the busy tone timer. If, on the other hand, there is PSTN interworking when an indication is received that the called party is busy, a busy tone is issued inband over the bearer path by the PSTN **125**, and is relayed through the wireless access communication unit **106** all the way to the CPE **105**.

If the wireless access communication unit **106** receives a DTAP Connect message from the network, indicating that a connection has been achieved, the wireless access communication unit **106** connects the bearer path if it has not already done so, and returns a DTAP Connect Acknowledgment message to the PSTN **125**.

In the event of an exception condition during call establishment, the wireless access communication unit **106** aborts the call establishment procedure. For a ground-start CPE trunk, it also passes a disconnect indication to the CPE **105**.

Call clearing is also preferably supported, and may be initiated either at the CPE **105** or the MSC **116**. The CPE **105** initiates call clearing by issuing a disconnect signal to the wireless access communication unit **106**. If the CPE **105** is the calling party for the call, the wireless access communication unit **106** commences timing of a call clearing guard timeout period (of, e.g., 600 milliseconds), at the end of which it releases the CPE trunk, clears the cal using DTAP signaling, and releases any over-the-air resources.

Call clearing is initiated on the network side (i.e., at the MSC **116**) by the transmission of a call clearing message from the network to the wireless access communication unit **106**. The response of the wireless access communication unit **106** depends upon whether the CPE trunk comprises a ground-start trunk or a loop-start trunk. If the CPE trunk is a ground-start trunk, then when the wireless access communication unit **106** receives a call clearing message from the PSTN **125**, it commences timing of a call clearing guard timeout period (of, e.g., 600 milliseconds), at the end of which it delivers a disconnect indication to the CPE **105**, and

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starts a permanent signal timer, the purpose of which is discussed further below. The wireless access communication unit **106** waits for a disconnect signal from the CPE **105** and, after receiving the disconnect signal, stops the permanent timer and releases the CPE trunk. In parallel, call clearing with the network is carried out to completion, and the over-the-air resources for the call get released.

If, on the other hand, the CPE trunk comprises a loop-start trunk, then when the wireless access communication unit **106** receives a call clearing message from the PSTN **125**, the wireless access communication unit **106** starts a permanent signal timer. The wireless access communication unit **106** waits for a disconnect signal from the CPE **105** and, after receiving the disconnect signal, stops the permanent timer and releases the CPE trunk. In parallel, call clearing with the network is carried out to completion, and the over-the-air resources for the call get released.

After network-initiated call clearing, if the user making the call through the CPE **105** remains off-hook, a permanent signal (extended off-hook) state will arise on the CPE trunk. The wireless access communication unit **106** handles this situation using the permanent signal timer referred to above. If the permanent signal timer expires without a disconnect signal being received from the CPE **105**, the wireless access communication unit **106** issues a reorder tone towards the CPE **105**. If, after a predetermined amount of time (e.g., 60 seconds) of issuing the reorder tone in this state, the wireless access communication unit **106** still has not detected a disconnect from the CPE **105**, the wireless access communication unit **106** removes the reorder tone and maintains the trunk in a busy state, pending the receipt of a disconnect from the CPE **105**.

The call progress tones may be summarized as follows. A dial tone is issued from the wireless access communication unit **106** to the CPE **105** when an off-hook transition is detected on an idle CPE trunk. A busy tone is issued (in the case of non-PSTN interworking only) when a DTAP Disconnect or Release Complete message is received at the wireless access communication unit **106**, with an indication of the called user being busy. A ringback tone is issued (in the case of non-PSTN interworking only) when a DTAP Alerting message is received. A reorder tone is issued during wireless access congestion conditions detected by the wireless access communication unit **106**, or upon expiration of a permanent signal timer, as described above.

The wireless access communication unit **106** may support transmission of DTMF tones during an active call. In the "forward" direction, the wireless access communication unit **106** detects DTMF tones generated by the CPE **105** and converts these tones into DTAP signaling towards the MSC **116**. The MSC **116**, upon receiving the DTAP DTMF signaling messages, re-generates the DTMF tones towards the PSTN **125**. In the "reverse" direction, DTMF tone signaling during an active call in such a manner is not generally supported by current GSM protocols.

The wireless access communication unit **106** preferably supports two main types of registration: network-level and base-level. For both network-level and base-level registration, the wireless access communication unit **106** performs registration of two different varieties, referred to as "normal" registration and "periodic" registration. Thus, in one embodiment of the invention, four types of registration are supported.

The two types of network-level registration supported by the wireless access communication unit **106** include normal network-level registration and network-periodic registration. Since each CPE trunk connected to the wireless access communication unit **106** is looked upon by the network as an individual subscriber, the registration procedure is typically carried out by the wireless access communication unit **106** on behalf of an individual CPE trunk. Each CPE trunk is separately registered according to its unique identifier (i.e., its IMSI). If the registration fails for a particular CPE trunk, the wireless access communication unit **106** marks the CPE trunk (or IMSI) as having failed registration.

Normal network-level registration is carried out when the wireless access communication unit **106** is powered up, or when the wireless access communication unit **106** changes location area—i.e., it starts communicating with a base station **109** that belongs to a location area different from the one in which it was previously registered. The registration procedure may comprise a normal location updating procedure on the A-interface **571**.

FIG. **28** is a call flow diagram illustrating normal network-level registration. As shown in FIG. **28**, upon power-up the wireless access communication unit **106** establishes a wireless communication channel (e.g., an over-the-air time slot in a TDMA system, such as described previously with respect to FIG. **25**). After acquiring the wireless communication channel, the wireless access communication unit **106** transmits a service request to the base station **109** specifying that a logical link is requested for the transmission of operations and maintenance data concerning the wireless access communication unit **106**. The service request may take the form of a Control Traffic Service Request (CT-SRQ) message. The base station **109** responds with a control traffic acknowledgment message. The wireless access communication unit **106** then transmits one or more control traffic transport messages to the base station **109** including information regarding the subscriber identifiers (i.e., IMSIs) of the CPE trunks and the equipment identifier (i.e., the IMEI) of the wireless access communication unit **106**. In response, the base station **109** enters the mapping between the IMEI and the IMSIs into its equipment/subscriber table (also referred to herein as its "IMEI table"). The base station **109** then formats an "alarm" message and sends an alarm to the OSS **122** with information identifying the wireless access communication unit **106** (i.e., its IMEI) and a message that the wireless access communication unit **106** has registered. After transmitting registration information, the wireless access communication unit **106** releases the logical link by transmitting a Control Traffic Release (CT-REL) message to the base station **109**, as shown in FIG. **28**.

In addition to normal network-level registration, the wireless access communication unit **106** also may perform periodic network-level registration. To do so, the wireless access communication unit **106**, after initial registration, periodically re-registers each IMSI (i.e., each CPE trunk), with a periodicity selected so that the duration between registrations is less than a prescribed time. For example, the prescribed time may be an amount of time that is less than the record retention time of the visitor location register (VLR) at the MSC **116**. The prescribed time should also be selected as long enough so as not to be burdensome to the wireless network. The periodic network-level registration translates to a periodic location updating procedure on the A-interface **571**. The periodicity is configurable in the GSM network infrastructure.

The wireless access communication unit **106** preferably also supports two types of base-level registration: normal registration and base-periodic registration. For base-level registration, each CPE trunk is separately registered according to its unique identifier (i.e., IMSI).

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Normal base-level registration is carried out when the wireless access communication unit **106** starts communicating with a base station **109** that is different from, but belongs to the same location area, as the one with which it was previously registered. Normal base-level registration allows the wireless access communication unit **106** to receive a new Surrounding Base Table, without having to change location areas. The base-level registration procedure translates to a normal location updating procedure on the A-interface.

The wireless access communication unit **106** also performs periodic base-level registration by periodically registering each IMSI (i.e., each CPE trunk) with the base station **109**. The periodicity of re-registration is controlled by the base station **109**. The periodicity is configurable through OAM&P, and may be selected such that the re-registration period is, for example, 16 seconds.

The base-periodic registration period can be used as a mechanism for monitoring the "health" of the wireless access communication unit **106**. In this aspect, the base-periodic registration may serve as a "heart-beat" for the base station **109** to know that the wireless access communication unit **109** is still in communication with it.

De-registration is performed by the system on behalf of each CPE trunk connected to the wireless access communication unit **106** when the wireless access communication unit **106** is powered off. The wireless access communication unit **106** when powered-off initiates a shut-down procedure that involves de-registration for each CPE trunk prior to actually powering down.

In case of a detected failure at the wireless access communication unit **106**, an alarm message is transmitted to report the failure to the operator. Upon detection of a fault, the wireless access communication unit **106** sends a fault notification (i.e., alarm message) to the base station **109** using a Control Traffic Transport (CT-TRA) message. The base station **109** then sends a fault report to the base station controller **112** using the base station object as the fault entity.

FIG. **29** is a call flow diagram illustrating alarm reporting. As shown in FIG. **29**, a wireless communication channel (e.g., a time slot in a TDMA system, such as described with respect to FIG. **25**) is first acquired if such a channel has not already been established. A service request is then sent to the base station **109** from the wireless access communication unit **106** specifying that a logical link is needed from operations and maintenance type data concerning the wireless access communication unit **106**. The service request takes the form of a Control Traffic Service Request (CT-SRQ) message. After receiving an control traffic acknowledgment message from the base station **109**, the wireless access communication unit **106** is free to send alarm information to the base station **109**. The alarm information may be conveyed in more than one physical message if necessary. After transmitting the alarm information, the wireless access communication unit **106** releases the logical link by sending a Control Traffic Release (CT-REL) message. The base station **109** then packages the alarm information into a base station alarm message format, and sends it to the operations management center (OMC) **120** and/or OSS **122**.

The format of an alarm message or alarm information sent by the wireless access communication unit **106** to the base station **109** may include multiple fields, including an identifier field, a failure type field, a status field, a failure cause field, and a log number field. The identifier field contains information identifying the wireless access communication unit **106**, such as an international mobile equipment identity (IMEI) number. The failure type field contains information indicating the type of failure that has occurred—e.g., communications failure, quality of service failure, processing failure, or equipment failure. The status field indicates whether the wireless access communication unit **106** is operational or degraded. The failure cause field indicates the reason for the failure, such as a radio unit failure, line card failure, or unknown failure, for example. The log number is used track the alarm. The wireless access communication unit **106** may maintain a log of triggered alarms, each having a corresponding log number. The logged alarm information may be used for debugging at a later time.

If the failure concerns a resource (i.e., hardware or software) at the wireless access communication unit **106**, then the alarm report preferably identifies the failing resource if it can be identified. A fault table may be maintained in the control section of the wireless access communication unit **106**, so as to keep track of alarms in force. When ever an alarm is reported, an entry is made in the fault table. The fault table helps prevent the same alarm from being reported twice. The fault table may be cleared on power-on or reset.

The base station **109** relays alarms initiated at the wireless access communication unit **106** to the base station controller **112**, using a base station alarm message format. The base station alarm message format may include multiple fields, such as a failure type field, fault severity field, failure cause field, and additional information field. The failure type field contains information indicating the type of failure (e.g., an equipment failure), the failure severity field indicates the seriousness of the failure (e.g., "warning"), the failure cause field indicates the source of the field (e.g., the wireless access communication unit **106**), and the additional information field generally contains details regarding the failure and, in the specific case of an alarm from the wireless access communication unit **106**, contains a copy of the alarm message received from the wireless access communication unit **106**.

FIG. **27** is a diagram illustrating authentication procedures, including division of functionality, in a preferred embodiment of the communication system **101**. As shown in FIG. **27**, an authentication triplet including a random number RAND, signed response SRES, and ciphering key K_c are stored in the VLR of the MSC **116**, after being transferred upon request from the HLR/AuC **123**. The random number RAND is sent to the wireless access communication unit **106**, whereupon it is applied along with the subscriber key value K_i to locally generate the signed response SRES and ciphering key K_c. The signed response SRES is returned by the wireless access communication unit **106** to the MSC **116** for comparison against the SRES stored at the VLR of the MSC **116**. The ciphering key K_c is used thereafter for ciphering transmissions across the wireless communication channel.

Bearer ciphering at the user end is performed at the wireless access communication unit **106**. Ciphering of bearer information on the network end is preferably carried out at the transcoding unit **115**. Ciphering of signaling messages (e.g., control traffic) may optionally be carried out. Further details regarding authentication and ciphering may be found in copending U.S. Pat. application Ser. No. 08/988,505 and U.S. Pat. 6,097,817, both of which have been previously incorporated herein by reference.

Operation of preferred embodiments of the invention will now be described in more detail, with reference as appropriate to the call flow diagrams depicted in FIGS. **12** through **22**.

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In accordance with a preferred embodiment of the invention as depicted in FIG. **1**, the wireless access communication unit **106** provides the capability to establish, maintain and tear down normal outgoing voice calls through a GSM-based segment that provides connectivity to the long distance functionality of the PSTN **125**. The wireless access communication unit **106** and other system components provide wireline transparency to a CPE **105** by supporting standard signaling functions on the CPE interface, including trunk supervisory signaling, address signaling, and provision of call progress tones to the CPE **105**.

As part of the initialization procedure after power-up, and preferably periodically thereafter, the wireless access communication unit **106** registers with a nearby base station **109** and also with the PSTN **125**. In this context, registration may generally be described as the process by which a subscriber (i.e., a CPE trunk **602**) connected to the wireless access communication unit **106** identifies itself to the network. Since each CPE trunk connected to the wireless access communication unit **106** is looked upon by the network as an individual subscriber, the registration procedure is typically carried out on behalf of an individual CPE trunk, and may need to be repeated for multiple CPE trunks.

FIG. **12** is a call flow diagram illustrating a network-level registration procedure. As a first step in the procedure illustrated in FIG. **12**, the wireless access communication unit **106** acquires a wireless communication channel (e.g., a time slot in a TDMA or TDD system, or a frequency channel in an FDD system, or other defined channel) to a nearby base station **109**. The wireless communication channel is acquired according to the particular protocol utilized by the wireless system. The wireless access communication unit **106** then performs a network-level registration procedure, according to the particular registration protocol utilized by the system. The registration procedure may involve, for example, a location updating procedure on the A-interface. The wireless access communication unit **106** performs network-level registration at regular intervals thereafter, with periodicity controlled by the network infrastructure. The wireless access communication unit **106** may also perform network-level registration if it starts communicating through a base station **109** in a different location area from the base station with which it had been previously communicating. After registration, the wireless communication channel is surrendered, and the MSC **116** initiates a resource release procedure, as illustrated in FIG. **12**.

In addition to network-level registration, the wireless access communication unit **106** may also perform periodic registration with the base station **109** at regular intervals, with a periodicity controlled by the base station **109**. For each registration attempt, the wireless access communication unit **106** acquires a wireless communication channel, registers, and then surrenders the wireless communication channel, unless a call is in progress. If a call is in progress, the wireless communication unit **106** need not acquire a new channel, but can, if possible under the particular wireless protocol, send registration information over the existing communication channel. In addition to periodic base-level registration, the wireless access communication unit **106** also performs initial registration with a base station **109** when it starts communicating through a base station different from but in the same location area as a base station with which it was previously communicating.

De-registration is performed by the system on behalf of each CPE trunk connected to the wireless access communication unit **106** when the wireless access communication unit **106** is powered off. FIG. **13** is a call flow diagram illustrating a network level de-registration procedure. As a first step in the procedure illustrated in FIG. **13**, the wireless access communication unit **106** acquires a wireless communication channel (e.g., a TDMA time slot) to a nearby base station **109**. The wireless communication channel is acquired according to the particular RF protocol utilized by the wireless system. The wireless access communication unit **106** then performs a network-level de-registration procedure, such as an IMSI detach procedure, according to the particular protocol utilized by the system. After de-registration, the wireless communication channel is surrendered, and the MSC **116** initiates a resource release procedure, as illustrated in FIG. **13**.

After registration by the wireless access communication unit **106**, outgoing calls may be placed to the PSTN **125** via the CPE **105**, wireless access communication unit **106** and base station subsystem. FIGS. **14** through **19** are call flow diagrams illustrating dial tone, digit transmission, digit analysis and call setup for outgoing calls under various types of CPE embodiments, including PBXs and KTSs with different levels of routing intelligence. FIG. **14**, for example, is a call flow diagram illustrating dial tone, digit transmission and digit analysis for a CPE **105** embodied as a "dumb" PBX—i.e., a PBX without the ability to route calls based on analysis of the dialed number. As shown in FIG. **14**, the user **102** (e.g., a telephone station, as shown in FIG. **1**) goes off-hook, sending an off-hook stimulus to the CPE **105** (i.e., the PBX). Upon detecting the off-hook signal, the PBX **105** issues a dial tone to the user **102**. The user **102** then dials an access code (i.e., a predetermined digit, such as '8') to access the wireless trunk offered by the wireless access communication unit **106**. Upon detecting the access code digit, the PBX **105** removes the dial tone and seizes a trunk connected to the wireless access communication unit **106**.

On detecting seizure of a trunk, the wireless access communication unit **106** issues a secondary dial tone to the user **102**. The secondary dial tone is delivered via the PBX **105** to the user **102**. In parallel to applying the secondary dial tone, the wireless access communication unit **106** commences acquisition of an over-the-air communication channel. In a TDMA or TDD system, for example, this step in the procedure generally entails seizing an over-the-air time slot.

Upon detecting the dial tone, the user **102** starts dialing the digits of the party to be called. The wireless access communication unit **106** detects the first digit, after which it removes the secondary dial tone. If acquisition of the over-the-air communication channel has not been completed by this time, the wireless access communication unit **106** stores the received digits in a temporary buffer.

After it successfully acquires an over-the-air communication channel, as shown in FIG. **14**, the wireless access communication unit **106** sends a control traffic service request (CT-SRQ) message to the base station **109** requesting service from the digit analysis application in the base station **109**. The base station **109** commences the digit analysis application, and returns a control traffic acknowledgment (CT-ACK) message to the wireless access communication unit **106**. The wireless access communication unit **106** then transmits the digits received from the user **102** to the base station **109** one-by-one as they are received from the user **102**. Each digit is sent as part of a control traffic transport (CT-TRA) message. The value of each digit may be indicated by a field of, e.g., four bits in the CT-TRA message. The base station **109** stores each received digit. After all address digits have been received at the base station **109**, the base station **109** detects that the dialing sequence is complete (according to its digit analysis), and returns a

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control traffic transport (CT-TRA) message to the central call processing unit **106**, with a message content indicating that dialing is complete. The wireless access communication unit **106** is then able to proceed with the launching of the call.

FIG. **15** is similar to FIG. **14**, but illustrates dial tone, digit transmission and digit analysis for a CPE **105** embodied as a "dumb" KTS—i.e., a key type system without the ability to route calls based on analysis of the dialed number. As shown in FIG. **15**, the user **102** first selects an outgoing line to the wireless access communication unit **106**. The user **102** then goes off-hook, sending an off-hook stimulus to the CPE **105** (i.e., the KTS). Upon detecting the off-hook signal, the CPE **105** seizes a trunk connected to the wireless access communication unit **106**. The wireless access communication unit **106** detects the trunk seizure, and in response issues a dial tone to the user **102**. In parallel with applying the dial tone, the wireless access communication unit **106** proceeds to acquire an over-the-air communication channel. In a TDMA or TDD system, this step generally entails seizing an over-the-air time slot.

When the user **102** detects the dial tone, the user **102** starts dialing the digits of the party to be called. After detecting the first digit, the wireless access communication unit **106** removes the dial tone. If acquisition of the over-the-air communication channel has not been completed by this time, the wireless access communication unit **106** stores the digits in a temporary buffer.

When it successfully acquires an over-the-air communication channel, the wireless access communication unit **106** sends a control traffic service request (CT-SRQ) message to the base station **109**, as shown in FIG. **15**, requesting service from the digit analysis application in the base station **109**. The base station **109** commences the digit analysis application, and returns a control traffic acknowledgment (CT-ACK) message to the wireless access communication unit **106**. The wireless access communication unit **106** then transmits the digits received from the user **102** to the base station **109** one-by-one as they are received from the user **102**. Each digit is sent as part of a control traffic transport (CT-TRA) message, as described with respect to FIG. **14**. The base station **109** stores each received digit. After all address digits have been received at the base station **109**, the base station **109** detects that the dialing sequence is complete (according to its digit analysis), and returns a control traffic transport (CT-TRA) message to the central call processing unit **106**, with a message content indicating that dialing is complete. The wireless access communication unit **106** is then able to proceed with the launching of the call.

FIG. **16**, in a fashion similar to FIGS. **14** and **16**, illustrates dial tone, digit transmission and digit analysis, but for a CPE **105** embodied as a PBX system which has sufficient built-in intelligence to route calls based on analysis of the dialed number. As shown in FIG. **16**, the user **102** first goes off-hook, sending an off-hook stimulus to the CPE **105** (i.e., the PBX). Upon detecting the off-hook signal, the CPE **105** issues a dial tone to the user **102**. The user **102** then dials an access code (i.e., a predetermined digit, such as '8' or '9') to access an outside line. Upon detecting the access code digit, the CPE **105** removes the dial tone and starts digit analysis. On detecting that the dialed number is the predetermined digit of the access code, the CPE **105** issues a secondary dial tone to the user **102**.

The user **102** then starts dialing the digits of the party to be called. Upon detecting the first digit from the user **102**, the CPE **105** removes the dial tone and starts digit analysis. After all the digits have been received by the CPE **105**, the CPE **105** determines from its digit analysis that a complete telephone number has been dialed. The CPE **105** also determines from its digit analysis whether or not the call is long distance (e.g., the first digit of the call to be placed following the access code is a '1'), and if the call is long distance seizes a trunk connected to the wireless access communication unit **106**. If the call is not long distance, the CPE **105** routes the call directly to the PSTN **125**.

Upon detecting seizure of a CPE trunk, the wireless access communication unit **106** issues a secondary dial tone to the user **102**. This secondary dial tone is muted by the CPE **105** on the user side—i.e., it is not passed along to the user **102**. In parallel with applying the secondary dial tone, the wireless access communication unit **106** proceeds to acquire an over-the-air communication channel. In a TDMA or TDD system, for example, this step generally entails seizing an over-the-air time slot. When the secondary dial tone is detected by the CPE **105**, the CPE **105** begins to outpulse to the wireless access communication unit **106** the digits earlier received from the user **102** as DTMF tones. Upon detecting the first digit (i.e., DTMF tone), the wireless access communication unit **106** removes the secondary dial tone. If acquisition of the over-the-air communication channel has not been completed by this time, the wireless access communication unit **106** stores the digits in a temporary buffer until such time as a wireless communication channel is obtained.

After it successfully acquires an over-the-air communication channel, the wireless access communication unit **106** sends a control traffic service request (CT-SRQ) message to the base station **109** requesting service from the digit analysis application in the base station **109**. The base station **109** commences the digit analysis application, and returns a control traffic acknowledgment (CT-ACK) message to the wireless access communication unit **106**. The wireless access communication unit **106** then transmits the digits received from the user **102** to the base station **109** one-by-one as they are received from the user **102**. Each digit is sent as part of a control traffic transport (CT-TRA) message. The base station **109** stores each received digit. After all address digits have been received at the base station **109**, the base station **109** detects that the dialing sequence is complete, and returns a control traffic transport (CT-TRA) message to the central call processing unit **106**, with a message content indicating that dialing is complete. The wireless access communication unit **106** is then able to proceed with the launching of the call.

FIG. **17** is similar to FIGS. **14**, **15** and **16**, but illustrates dial tone, digit transmission and digit analysis for a CPE **105** embodied as a key type system (KTS) which has sufficient built-in intelligence to route calls based on analysis of the dialed number. As shown in FIG. **17**, the user **102** first goes off-hook, sending an off-hook stimulus to the CPE **105** (i.e., the KTS). Upon detecting the off-hook signal, the CPE **105** issues a dial tone to the user **102**. The user **102** then starts dialing the digits of the party to be called. Upon detecting the first digit from the user **102**, the CPE **105** removes the dial tone and starts digit analysis.

After all the digits have been received by the CPE **105**, the CPE **105** determines from its digit analysis that a complete telephone number has been dialed. The CPE **105** also determines from its digit analysis whether or not the call is long distance (e.g., the first digit dialed is a '1'), and if the call is long distance seizes a trunk connected to the wireless access communication unit **106**. If the call is not long distance, the CPE **105** routes the call directly to the PSTN **125**.

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When a trunk is seized, the wireless access communication unit **106** issues a secondary dial tone to the CPE **105**. This secondary dial tone is muted by the CPE **105** on the user side—i.e., it is not passed to the user **102**. In parallel with applying the secondary dial tone, the wireless access communication unit **106** proceeds to acquire an over-the-air communication channel. In a TDMA or TDD system, this step generally entails seizing an over-the-air time slot. When the secondary dial tone is detected by the CPE **105**, the CPE **105** begins to outpulse the digits earlier received from the user **102** to the wireless access communication unit **106**. Upon detecting the first digit, the wireless access communication unit **106** removes the secondary dial tone. If acquisition of the over-the-air communication channel has not been completed by this time, the wireless access communication unit **106** stores the digits in a temporary buffer.

After it successfully acquires an over-the-air communication channel, the wireless access communication unit **106** sends a control traffic service request (CT-SRQ) message to the base station **109** requesting service from the digit analysis application in the base station **109**. The base station **109** commences the digit analysis application, and returns a control traffic acknowledgment (CT-ACK) message to the wireless access communication unit **106**. The wireless access communication unit **106** then transmits the digits received from the user **102** to the base station **109** one-by-one as they are received from the user **102**. Each digit is sent as part of a control traffic transport (CT-TRA) message. The base station **109** stores each received digit. After all address digits have been received at the base station **109**, the base station **109** detects that the dialing sequence is complete, and returns a control traffic transport (CT-TRA) message to the central call processing unit **106**, with a message content indicating that dialing is complete. The wireless access communication unit **106** is then able to proceed with the launching of the call.

If the wireless access communication unit **106** issues a dial tone (or a secondary dial tone) and does not receive digits from the CPE **105** within a preset amount of time, a dial timeout condition will occur. In such a case, the wireless access communication unit **106** releases any over-the-air communication channel that it may have seized and issues permanent treatment to the user (i.e., performs a de-registration procedure, if necessary, and causes the MSC **116** to release any resources allocated for the call).

FIGS. **18** and **19** are call flow diagrams illustrating successful call setup procedures in two scenarios. FIG. **18** illustrates a call flow for a successful CPE-originated normal (i.e., non-emergency) call setup sequence, with non-PSTN interworking at the MSC **116**. As depicted in FIG. **18**, provision of the dial tone, transmission of digits and digit analysis is carried out according to any of the scenarios illustrated in the call flow diagrams of FIGS. **14** through **17**. In each instance the call flow terminates with an end of dialing indication from the base station **109** to the wireless access communication unit **106**. Upon receiving the end of dialing indication from the base station **109**, the wireless access communication unit **106** initiates a mobility management connection establishment procedure for a normal call. This procedure results in an SCCP link being established for the call across the A-interface **571** (assuming a GSM system), and further results in a mobility management connection being set up with the MSC **116** for handling the call. Part of this procedure may, if desired, entail authentication and cipher mode setting procedures for the call.

After completion of the mobility management connection procedure, the wireless access communication unit **106** sends a direct transfer application part (DTAP) Setup message to the base station **109**, as illustrated in FIG. **18**. The DTAP Setup message contains an empty called party address field, and is directed towards the MSC **116**. The base station **109** intercepts the DTAP Setup message and fills in the called address field with the digits received from the wireless access communication unit earlier during the digit analysis step. The base station **109** then forwards the DTAP Setup message, via the base station controller **112**, to the MSC **116**. The MSC **116** acknowledges the receipt of the DTAP Setup message by sending a DTAP Call Proceeding message to the wireless access communication unit **106**, as illustrated in FIG. **18**.

A bearer resource assignment procedure is then executed on each interface of the wireless fixed-access system, starting from the A-interface **571** and progressing to the O-interface **560**. The bearer resource assignment procedure results in bearer channels being assigned on the A-interface **571**, N-interface **562** and O-interface **560**, and a switched connection being set up through the base station controller **112**.

After the bearer resource assignment procedure is complete, the MSC **116** sends a DTAP Alerting message to the wireless access communication unit **106**. The wireless access communication unit **106** provides a ringback tone to the user **102**, via the inband path through the CPE **105** (i.e., the PBX or KTS, or other similar system). When the called party answers the call, the MSC **116** sends a DTAP Connect message to the wireless access communication unit **106**. At that point the wireless access communication unit **106** attaches its speech path and removes the ringback tone to the user **102**. The wireless access communication unit **106** responds to the MSC **116** with a DTAP Connect Acknowledgment message, and the call is then in a conversation state.

FIG. **19**, like FIG. **18**, illustrates a call flow for a successful CPE-originated normal call setup sequence, but with PSTN interworking at the MSC **116**. As depicted in FIG. **19**, provision of the dial tone, transmission of digits and digit analysis is carried out according to any of the scenarios illustrated in the call flow diagrams of FIGS. **14** through **17**. Upon receiving an end of dialing indication from the base station **109**, the wireless access communication unit **106** initiates a mobility management connection establishment procedure for a normal call. Similar to the call flow of FIG. **18**, this procedure results in an SCCP link being established for the call across the A-interface (assuming a GSM system), and further results in a mobility management connection being set up with the MSC **116** for handling the call. Part of this procedure may, if desired, entail authentication and cipher mode setting procedures for the call.

After completion of the mobility management connection procedure, the wireless access communication unit **106** sends a DTAP Setup message to the base station **109**. The DTAP Setup message contains an empty called party address field, and is directed towards the MSC **116**. The base station **109** intercepts the DTAP Setup message and fills in the called address field with the digits received from the wireless access communication unit earlier during the digit analysis step. The base station **109** then forwards the DTAP Setup message, via the base station controller **112**, to the MSC **116**. The MSC **116** acknowledges the receipt of the DTAP Setup message by sending a DTAP Call Proceeding message to the wireless access communication unit **106**, as illustrated in FIG. **18**. A bearer resource assignment procedure is then executed on each interface of the wireless fixed-access system, starting from the A-interface and progressing to the O-interface, similar to the call flow of FIG.

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18. The bearer resource assignment procedure results in bearer channels being assigned on the A-interface, N-interface and O-interface, and a switched connection being set up through the base station controller **112**.

After the bearer resource assignment procedure is complete, the MSC **116** sends a DTAP Progress message to the wireless access communication unit **106**, indicating interworking with the PSTN **125**. The wireless access communication unit **106** attaches its speech path at this point. The network senses the ringback tone over the connected speech path, and the ringback tone is relayed by the wireless access communication unit **106** to the user **102**, via the CPE **105** (i.e., the KTS or PBX, or other similar system). When the called party answers the call, the network removes the ringback tone. The MSC **116** sends a DTAP Connect message to the wireless access communication unit **106**. The wireless access communication unit **106** responds with a DTAP Connect Acknowledgment message, and the call then moves to a conversation state.

In either call flow scenario depicted in FIG. **18** or **19**, if the called party is busy, the call will generally be rejected. In the case of non-PSTN interworking, a busy tone is sent from the wireless access communication unit **106** to the user **102** in response to a DTAP Disconnect message from the MSC **116**, and a DTAP release procedure is initiated. When an on-hook signal is detected from the user **102**, the wireless access communication unit **106** initiates a call resource release procedure. In the case of PSTN-interworking, the busy tone is sent from the PSTN **125**. When the CPE **105** detects an on-hook signal from the user **102**, it sends a disconnect message to the wireless access communication unit **106**, which then initiates a DTAP release procedure followed by a call resource release procedure.

In the case of ISDN interworking on the long-distance network interface, the wireless access communication unit **106** generates the appropriate call progress tones to the CPE **105** based on DTAP signaling received from the MSC **116**. Such call progress tones include busy tones and ringback tones, for example. In case of PSTN interworking, these call progress tones are generated by the PSTN **125** and passed inband to the wireless access communication unit **106**, which relays them to the CPE **105**. The dial tone is always generated by the wireless access communication unit **106**. Also, a reorder tone may be generated by the wireless access communication unit **106** during congestion conditions or as part of permanent treatment.

FIGS. **20** through **22** are call flow diagrams depicting various call scenarios. FIG. **20** illustrates a call flow for a call waiting situation during an active call. As illustrated in FIG. **20**, a first user is engaged in an active call over the network. A second user desires to place a call to the first user, and causes an off-hook signal to be generated. The CPE **105** (i.e., KTS, PBX or similar type system) detects the off-hook signal, and responds with a dial tone. The second user dials the telephone number of the first user, and because the call is not long distance (but rather is station-to-station) it is handled by the CPE **105** itself rather then sending it to the wireless access communication unit **106**. Upon detecting the first digit from the second user, the CPE **105** removes the dial tone.

After the number is dialed the CPE **105** attempts to deliver the call to the first user. Knowing that the first user is already engaged in a call, the CPE **105** issues a call waiting tone to the first user, indicating to the first user that another caller is attempting contact. The CPE **105** also issues a ringback tone to the second user, to indicate that the first user is being paged.

If the first user responds to the call waiting tone with a hook flash, the CPE **105** detects the hook flash signal and places the initial conversation on hold. The CPE **105** then connects the first user and the second user in a conversation. The first user can then toggle between conversations by using the hook flash signal, as illustrated in FIG. **20**.

FIG. **21** is a call flow diagram illustrating a three-way call setup scenario. At the start of the call flow shown in FIG. **21** it is assumed that a first user is already engaged in an active call over the network. The first user then decides to place a station-to-station call to a second user. To do so, the first user delivers a hook-flash signal to the CPE **105**. The CPE **105** responds by providing a recall dial tone to the first user, and by placing the original conversation on hold. The first user then dials the second user's extension. When the CPE **105** detects the first digit of the dialed extension, it terminates the recall dial tone.

After the dialing of the extension is complete, the CPE **105** attempts to deliver the call to the second user. At the same time, the CPE **105** delivers a ringback tone to the first user. When the CPE **105** receives an off-hook signal from the second user, it terminates the ringback tone to the first user. The first user and second user are then able to converse in an active call. Upon detecting a hook flash signal from the first user, the CPE **105** connects the two calls so as to effectuate a three-way call.

In each of the call flow situations of FIGS. **20** and **21**, the call feature is provided to the end users in a transparent manner. Likewise, the calls are effectuated over the PSTN **125** in a manner transparent to it as well.

FIG. **22** illustrates a DTMF signaling procedure during an active call from the CPE **105** to the PSTN **125**. On detecting a DTMF tone from the CPE **105** which exceeds a predefined minimum DTMF timeout period (e.g., 20 milliseconds), the wireless access communication unit **106** sends a DTAP Start DTMF message to the MSC **116**. The DTAP Start DTMF message indicates that a digit is being sent. When the MSC **116** receives this message, it re-generates the DTMF tone towards the network, and returns a DTAP Start DTMF Acknowledgment message to the wireless access communication unit **106**.

When the wireless access communication unit **106** detects the DTAP Start DTMF Acknowledgment message, it sends a DTAP Stop DTMF message to the MSC **116**. Upon receiving the DTAP Stop DTMF message, the MSC **116** stops sending the DTMF tone towards the network. The MSC **116** returns a DTAP Stop DTMF Acknowledgment message to the wireless access communication unit **106**. The procedure is repeated for each DTMF tone sent by the CPE **105**.

The DTAP Start DTMF message and DTAP Stop DTMF message are both messages supported by existing GSM protocol. The wireless access communication unit **106** makes use of the DTAP Start DTMF message and DTAP Stop DTMF message to transfer information relating to DTMF tones during an active call, in a transparent manner to the base station **109** and base station controller **112**. The DTMF tones can thereby be related across the wireless communication channel and regenerated at the MSC **116** before being relayed to the network.

Both normal and emergency calls can be handled by the preferred communication system **101** of FIG. **1**. Emergency calls (i.e., "911" calls) are preferably routed by the CPE **105** directly to the PSTN **125**. This may be accomplished in the same manner other calls are routed. For example, the user may dial a PSTN access code for an emergency call (in the

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case of a PBX), or may select a PSTN trunk from the desksets (in the case of a KTS). Alternatively, the CPE **105** can be configured to route emergency calls to a PSTN trunk by analyzing the received digits. It may nevertheless be desirable to provide the wireless access communication unit **106** with the capability to establish, maintain and tear down emergency calls if it receives a trigger to initiate such a call. The wireless access communication unit **106** may perform these emergency call operations using a GSM-based segment.

FIGS. **23** and **24** are frequency distribution diagrams illustrating alternative spectral allocations for wireless resources in two particular embodiments of the invention. FIG. **23** shows a possible spectral allocation over an available over-the-air frequency bandwidth of 5 MHz. As shown in FIG. **23**, a 5 MHz bandwidth may be divided into three sub-bands having center frequencies spaced 1.6 MHz apart, and having 0.9 MHz spacing from each peripheral center frequency to the outer edge of the 5 MHz bandwidth. FIG. **24** shows a possible spectral allocation over an available over-the-air frequency bandwidth of 6.6 MHz. As shown in FIG. **24**, a 6.6 MHz bandwidth may be divided into four sub-bands having center frequencies spaced 1.6 MHz apart, and having 0.9 MHz spacing from each peripheral center frequency to the outer edge of the 6.6 MHz bandwidth. In an embodiment according to either FIG. **23** or FIG. **24**, a wireless transmitter (at either the base station **109** or the wireless access communication unit **106**) transmits a signal, preferably a direct sequence spread spectrum signal, having a maximum bandwidth of approximately 1.6 MHz. The particular spectral allocations in FIGS. **23** and **24** are meant to be illustrative only, and illustrate possible spectral allocations for a preferred spread spectrum wireless communication path; however, any spectral allocation may be made serving the purposes of the particular wireless connection utilized between the base station **109** and the wireless access communication unit **106**.

While one or more embodiments have been described above in accordance with various aspects of the present invention, a number of variations of these embodiments exist incorporating the same or similar principles of operation as described herein. For example, it will be apparent to one skilled in the art that the functionality of the CPE **105** and the wireless access communication unit **106** can be combined into a single unit. Also, one or more telephone stations **102** can be connected directly to the wireless access communication unit **106**, bypassing the CPE **105**. Also, the CPE **105** need not be connected to the telephone stations **102** with telephone lines, but may be wirelessly connected thereto (i.e., a wireless PBX).

A local area communication system according to certain aspects of the present invention may be comparatively easy to deploy in remote and/or rural areas, in contrast to systems requiring landline connections from a PBX or KTS to the network. With the addition of connecting the wireless access communication unit to the PBX or KTS, a remotely-located local area communication system can obtain benefits of a wireless network (including long distance access) for relatively little extra deployment effort.

While preferred embodiments of the invention have been described herein, many variations are possible which remain within the concept and scope of the invention. Such variations would become clear to one of ordinary skill in the art after inspection of the specification and the drawings. The invention therefore is not to be restricted except within the spirit and scope of any appended claims.

What is claimed is:

1. A method of communication, comprising the steps of:

establishing a wireless connection between a wireless access communication unit and a base station subsystem of a cellular network, said wireless access communication unit connected to a plurality of non-wireless units;

performing connection management and mobility management functions between said wireless access communication unit and a mobile switching center using GSM connection management and GSM mobility management protocols end-to-end between said wireless access communication unit and said mobile switching center, said connection management and mobility management functions providing at least call set-up, maintenance and release functions for each of said non-wireless units;

transporting call data over said wireless connection between said wireless access communication unit and said base station subsystem using a non-GSM over-the-air physical layer protocol; and

transporting said call data between said base station subsystem and said mobile switching center using a GSM protocol.

2. The method of claim **1**, wherein

said base station subsystem comprises a plurality of base stations connected to a base station controller,

said step of transporting call data over said wireless connection between said wireless access communication unit and said base station subsystem using a non-GSM over-the-air physical layer protocol comprises the step of transporting call data between said wireless access communication unit and a base station of said base station subsystem, and

said step of transporting said call data between said base station subsystem and a mobile switching center using a GSM protocol comprises the step of transporting said call data between said base station controller and said mobile switching center using said GSM protocol.

3. The method of claim **2**, further comprising the step of establishing a plurality of bearer paths between said wireless access communication unit and said mobile switching center, each bearer path corresponding to one of said non-wireless units connected to said wireless access communication unit.

4. The method of claim **3**, further comprising the step of establishing and maintaining a plurality of SCCP links between said base station controller and said mobile switching center, one SCCP link for each of said bearer paths.

5. The method of claim **1**, wherein said step of transporting call data over said wireless connection between said wireless access communication unit and said base station subsystem using a non-GSM over-the-air physical layer protocol comprises the step of transporting said call data using an IS-661 format.

6. The method of claim **1**, wherein said step of transporting call data over said wireless connection between said wireless access communication unit and said base station subsystem using a non-GSM over-the-air physical layer protocol comprises the steps of:

assigning, from among a plurality of time slots of a time frame, one or more duplex time slots to said wireless access communication unit, one of said duplex time slots being assigned for each non-wireless communication unit desiring to communicate over said wireless connection;

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transmitting, over a first frequency band, user-to-base traffic messages from the wireless access communication unit to a base station of said base station subsystem during a user transmission segment in each of said duplex time slots; and

transmitting, over a second frequency band, base-to-user traffic messages from said base station to said wireless access communication unit during a base transmission segment in each of said duplex time slots.

7. The method of claim **6**, wherein said user transmission segment and said base transmission segment of each duplex time slot are separated by one-half the duration of said time frame.

8. A method of communication, comprising the steps of:

establishing a wireless connection between a wireless access communication unit and a base station of a cellular network, said wireless access communication unit connected to a plurality of non-wireless units;

performing connection management and mobility management functions between said wireless access communication unit and a mobile switching center using GSM connection management and GSM mobility management protocols end-to-end between said wireless access communication unit and said mobile switching center, said connection management and mobility management functions providing at least call set-up, maintenance and release functions for each of said non-wireless units;

transporting call data over said wireless connection between said wireless access communication unit and said base station using a non-GSM over-the-air physical layer protocol;

transmitting call data received from said wireless access communication unit over a backhaul connection from said base station to a base station controller;

relaying said call data received from said wireless access communication unit from said base station controller to said mobile switching center using a GSM protocol;

transmitting from said mobile switching center to said base station controller call data intended for said wireless access communication unit using said GSM protocol; and

relaying said call data intended for said wireless access communication unit to said base station over said backhaul connection.

9. The method of claim **8**, wherein said step of transporting call data over said wireless connection between said wireless access communication unit and said base station using a non-GSM over-the-air physical layer protocol comprises the step of transporting said call data using an IS-661 protocol.

10. The method of claim **8**, wherein said step of transporting call data over said wireless connection between said wireless access communication unit and said base station using a non-GSM over-the-air physical layer protocol comprises the steps of:

assigning, from among a plurality of time slots of a time frame, one or more duplex time slots to said wireless access communication unit, one of said duplex time slots being assigned for each non-wireless communication unit desiring to communicate over said wireless connection;

transmitting, over a first frequency band, user-to-base traffic messages from the wireless access communication unit to said base station during a user transmission segment in each of said duplex time slots; and

transmitting, over a second frequency band, base-to-user traffic messages from said base station to said wireless access communication unit during a base transmission segment in each of said duplex time slots.

11. The method of claim **10**, wherein said user transmission segment and said base transmission segment in each duplex time slot are separated by one-half the duration of said time frame.

12. The method of claim **8**, wherein said step of transporting call data over said wireless connection between said wireless access communication unit and said base station using a non-GSM over-the-air physical layer protocol comprises the step of transmitting signaling messages between said wireless access communication unit and said base station.

13. The method of claim **8**, wherein said step of transporting call data over said wireless connection between said wireless access communication unit and said base station using a non-GSM over-the-air physical layer protocol comprises the step of transmitting bearer traffic messages between said wireless access communication unit and said base station for each non-wireless unit communicating over said wireless connection.

14. A communication system, comprising:

a base station;

a wireless access communication unit connected to a plurality of non-wireless units, said wireless access communication unit providing a communication path between said base station and said non-wireless units, said communication path including a wireless connection over which said wireless access communication unit and base station communicate using a non-GSM over-the-air physical layer protocol;

a base station controller connected to said base station; and

a mobile switching center connected to said base station controller, said mobile switching center and said base station controller communicating using a GSM protocol, said mobile switching center and said wireless access communication unit performing connection management and mobility management functions using GSM connection management and GSM mobility management protocols end-to-end, said connection management and mobility management functions providing at least call set-up, maintenance and release functions for each of said non-wireless units.

15. The communication system of claim **14**, wherein said non-GSM over-the-air physical layer protocol comprises an IS-661 over-the-air protocol.

16. The communication system of claim **14**, wherein said base station comprises at least two backhaul transceivers.

17. The communication system of claim **16**, wherein said backhaul transceivers comprise logical terminal endpoints, each backhaul transceiver supporting a first logical link for traffic signaling and a second logical link for operations, administration and management signaling.

18. The communication system of claim **17**, wherein said base station multiplexes said first logical link and said second logical link of each of said backhaul transceivers onto a single time slot for communication to said base station controller.

19. The communication system of claim **17**, wherein functional entities of said base station are addressable using service access point identifiers.

20. The communication system of claim **14**, wherein said base station controller and said wireless access communication unit comprise endpoints for voice encoding and decoding.

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21. The communication system of claim 14, wherein said base station controller and said wireless access communication unit comprise endpoints for encryption and decryption of bearer traffic.

22. The communication system of claim 14, wherein said base station controller and said wireless access communication unit comprise endpoints for forward error correction.

23. The communication system of claim 14, further comprising a transcoding unit, wherein said mobile switching center is connected to said base station controller through said transcoding unit.

24. The communication system of claim 14, wherein said base station controller and said mobile switching center communicate across a GSM A-interface.

25. The communication system of claim 14, wherein said wireless access communication unit is connected to said non-wireless units through a local area telephone switch.

26. The communication system of claim 25, wherein said local area telephone switch comprises either a private branch exchange (PBX) or key telephone system (KTS).

27. The communication system of claim 25, wherein said wireless access communication unit comprises

a plurality of subscriber ports connected to said local area telephone switch over a plurality of trunks;

a plurality of user interfaces connected to said subscriber ports, one user interface for each subscriber port;

a radio transceiver; and

a controller connected to said user interfaces and said radio transceiver, said controller managing the transfer of data between said user interfaces and said radio transceiver.

28. The communication system of claim 27, wherein said user interfaces are individually addressable.

29. The communication system of claim 27, wherein said base station controller and said mobile switching center maintain a plurality of SCCP links, one SCCP link for each user interface over which a call is connected from one of said non-wireless units.

30. The communication system of claim 27, wherein said wireless access communication unit sets up and maintains calls from said non-wireless units to said mobile switching center via said base station and said base station controller.

31. The communication system of claim 14, wherein said base station supports a multiple access communication protocol, said base station establishing wireless communication paths with mobile user stations upon demand.

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