Packet Mode in Wireless Networks: Overview of Transition to Third Generation

Behcet Sarikaya, University of Aizu

ABSTRACT

This article presents an overview of packet mode data transfer in cellular networks. Leading 2G + cellular networks of GSM GPRS and IS-95B are introduced. Architecture and protocol layers in two leading third-generation cellular network proposals, cdma2000 and WCDMA, are presented. Mobile IP support in various cellular networks is discussed next. With efficient support of Mobile IP in cellular networks, seamless integration of cellular networks with the Internet is expected to be reached at a rapid pace.

INTRODUCTION

Existing wireless networks are mostly digital and support voice communication at a low bit rate of 9.6–32 kb/s. Fueled by the explosive growth of the Internet, applications are demanding that higher capacity, higher data rates, and advanced multimedia services be supported in the near future. The evolution to higher data rates and more advanced services occurs in two steps. The first step is the emergence of 2G + systems in which second-generation (2G) systems such as Global System for Mobile Communications (GSM) and IS-95 are extended to provide high-speed data communications either without changing the air interface or by using improved coding techniques. The second step is to provide higher capacity, data rates, and multimedia services. Wideband codedivision multiple access (WCDMA) standard proposals such as the cdma2000 system include a greatly enhanced air interface to support wider bandwidths for improved capacity and higher data rates.

In a cellular network, there are radio ports with antennas connected to base stations (BSs) serving the user equipment, the mobile stations (MSs). The communication from the MS to the BS is the uplink, and from the BS to the MS the downlink. The downlink is contentionless, but the uplink is accessed by several MSs; therefore, another important characteristic is the multiple access technique used for its uplink. Frequency- division multiple access (FDMA), time-division multiple access (TDMA), and CDMA are the most widely used physical-layer multiple access techniques.

The infrastructure of cellular networks includes mobile switching centers (MSCs), which control one or more BSs and interface them to the wired public switched telephone network, and a central home location register (HLR) and visiting location register (VLR) for each MSC. The HLR and VLR are databases that keep the registered and present locations of MSs to be used in handoffs (the process of handing a call over to the new cell when an MS moves).

The article continues by introducing 2G + systems. We then discuss third-generation (3G) wireless cellular networks, which are expected to be deployed beginning this year. We also have a section on Mobile IP support. Finally, we present some concluding remarks.

2G + SYSTEMS

Two examples of the macrocellular packet mode standards are GSM's General Packet Radio System (GPRS), a TDMA-based system, and IS-95A's IS-95B, a CDMA-based system. Higher-capacity transmission is achieved with multislot mode in TDMA and multiple codes in CDMA-based systems. In some cases, a higherlevel modulation format is used to increase the rate of transmission.

THE EVOLUTION OF GSM PACKET MODE

GPRS — GPRS is the packet mode extension to GSM. It uses the same air interface but with a new physical channel called a 52-multiframe, which is made of two 26 control multiframes of voice mode GSM. Packet mode control and data channels are mapped into different slots of the 52-multiframe, which takes 240 ms. 52-multiframe consists of 12 blocks (B0–B11) of four frames to which several packet mode logical channels can be mapped, and four additional frames.

The architecture of GPRS is shown in Fig. 1. The serving GPRS support node (SGSN) is in charge of one or more GPRS BSs. The base station controller (BSC) monitors and controls several BSs or base transceiver stations (BTSs). The BSC and its BTSs form a base station sub-

Editorial liaison: M. Ulema system (BSS). A BTS and the MSs in its control form a cell. The gateway GPRS support node (GGSN) is for interconnection with the Internet. The registration of packet mode MSs is done with the architectural entities, the MSC/VLR and HLR.

Logical channels of GPRS are the packet common control channel (PCCCH), which comprises logical channels for common control signaling used for packet data; packet random access channel (PRACH) - uplink only, which is used by an MS to initiate uplink transfer for sending data or signaling information; packet paging channel (PPCH) -- downlink only, which is used to page an MS prior to downlink packet transfer; packet access grant channel (PAGCH) - downlink only, which is used in the packettransfer establishment phase to send resource assignment to an MS prior to packet transfer; and packet broadcast control channel (PBCCH) - downlink only, which is used to broadcast packet-data-specific system information. The packet data traffic channel (PDTCH) is a channel allocated for data transfer. It is temporarily dedicated to one MS. In multislot operation, one MS may use multiple PDTCHs in parallel for individual packet transfer. All PDTCHs are unidirectional, either uplink (PDTCH/U) for a mobile-originated packet transfer or downlink (PDTCH/D) for a mobile-terminated packet transfer. A packet associated control channel (PACCH) conveys signaling information related to a given MS. The PACCH also carries resource assignment and reassignment messages, assigning a capacity for PDTCH(s) and for further occurrences of the PACCH.

A multislot MS can be assigned up to eight slots in any frame of any of 12 blocks. In a given cell up to four downlink/uplink pairs of 52-multiframes can be generated on four different pairs of frequencies.

Protocol layering in GRPS is as follows. The Subnetwork Dependent Convergence Protocol (SNDCP) does the convergence. Logical link control (LLC) is the upper layer of medium access control. Radio link control (RLC) and the medium access control (MAC) protocol provide reliable access to the radio link.

Transmission/reception data flow is shown in Fig. 2. A temporary block flow (TBF) is a physical connection used by the two radio



Figure 1. GPRS architecture.

resource (RR) entities to support the unidirectional transfer of LLC PDUs on packet data physical channels. The TBF is allocated some radio resources on one or more PDCHs and comprises a number of RLC/MAC blocks carrying one or more LLC PDUs. A radio block consists of a 1-byte MAC header, followed by RLC data or an RLC/MAC control block and terminated by a 16-bit block check sequence (BCS). It is carried by four normal bursts (i.e., it is 57 bytes long). A TBF is temporary and is maintained only for the duration of the data transfer. Each TBF is assigned a temporary flow identity (TFI) by the network which is unique in both directions.

The GRPS allows a maximum of eight slots per frame to be allocated to the PDTCH on the downlink and uplink on all radio blocks B0-B11. On the downlink, an IP datagram of 1500 bytes, to be transmitted as an LLC PDU, is fragmented into 29 RLC blocks. These blocks can be transmitted using a total of 116 consecutive bursts. During one 52-multiframe with an 8 slots/frame dynamic allocation scheme, 3.3 such IP datagrams can be transmitted, yielding a maximum data rate of 165.5 kb/s for GPRS downlink.

On the uplink, an IP datagram of 1500 bytes, to be transmitted as an LLC PDU, is fragmented into 31 RLC blocks which can be transmitted in 124 slots. During one 52-multiframe with an 8 slots/frame dynamic allocation scheme, three such IP datagrams can be transmitted, yielding a maximum data rate of 154 kb/s for GPRS uplink.



Figure 2. GPRS downlink/uplink segmentation [1].

Wideband CDMA is being standardized by a consortium of leading standardization organization of the United States, Europe, and Asia, and the resulting standards are being harmonized by ITU-R in its IMT-2000 harmonization initiative.

THE EVOLUTION OF IS-95 TO PACKET MODE DATA

IS-95B — IS-95B is the packet mode version of direct sequence CDMA standard IS-95A. IS-95B supports multiple codes per MS on both the downlink and uplink.

Physical channels on the downlink are the pilot channel, paging channels, and traffic channels; and on the uplink, access and traffic channels. The BS always generates the pilot channel. One synchronization channel and up to seven paging channels can be generated, in which case 55 code channels to be used as traffic channels are generated. Up to 63 traffic channels can be generated at the downlink. Each traffic channel contains one fundamental code channel (FCC) and up to seven supplemental code channels (SCCs). The pilot channel provides CDMA infrastructural support such as demodulation and power control measurements. The sync channel provides synchronization information such as paging channel data rate and system time. It operates at 1.2 kb/s rate.

On the uplink, the access channel, like the PACCH of GPRS, is used by an MS to initiate a call, to respond to a paging channel message from the BS, and for location update. Each access control channel is associated with a downlink paging channel; therefore, there can be up to seven access channels. Access channels support 4.8 kb/s data rate only. Traffic channels consist of a single FCC and up to seven SCCs per user. A total of 64 uplink physical channels can be generated in a cell on a given frequency. Downlink/uplink SCCs can use only the full rates of 9.6 or 14.4 kb/s.

The data link layer in IS-95B is organized as the multiplexing sublayer, layer 2 for primary traffic, for example, the radio link control protocol (RLP) and upper layers for primary traffic containing the LLC protocol. RLC provides reliable data link control and stream-oriented delivery of LLC data. The radio link is divided into 20 ms time slots. During a time slot an MS can transmit/receive packets containing 192 bits, of which 172 are information bits at full rate of 9.6 kb/s, or 288 bits, of which 267 are information bits at 14.4 kb/s using one FCC and up to seven SCCs.

Packet mode message exchange is originated by an MS using fundamental code channels. A BS may decide to assign some supplemental code channels during packet mode communication. In this case the BS sends a supplemental channel assignment message and then begins transmitting on the downlink SCCs. If the MS requires more bandwidth, it sends a supplemental channel request message to the BS on the reverse FCC. The BS replies with a supplemental channel assignment message which is forwarded to the FCC. The MS then begins transmitting on the assigned reverse SCCs.

In IS-95B the segmentation and reassembly of packet data are done at the RLP layer. For rate set 1 (9.6 kb/s) the maximum length is 19 bytes, and for rate set 2 the maximum length is 31 bytes. Format B data frames have a sequence field of 8 bits and 20 octets of data for rate 1, and 32 octets of data for rate 2. An IP datagram of 1500 bytes will be segmented into 79 RLP format A data frames at 9.6 kb/s and 49 frames at 14.4 kb/s. Assuming one FCC and seven SCCs are to be used, it takes 10 frames for 9.6 and seven slots for 14.4 rate sets to completely transmit this datagram. The resulting maximum downlink data rates are 60 and 86 kb/s for rates sets 1 and 2, respectively.

In the uplink, the MS sends an access probe in one R-ACH. An R-ACH is organized in slots of a multiple number of 20 ms frames (e.g., five frames or 100 ms slots). After transmitting the access probe, the MS waits a specified period, T_A , which has a minimum value of 160 ms to receive an acknowledgment. If an acknowledgment is received, packet transmission can start on the FCC and SCCs. The resulting maximum uplink data rates are 26 and 30 kb/s for rates sets 1 and 2, respectively. These rates are extremely low compared to downlink rates. However, if the MS continues to send subsequent IP datagrams after the access probe, data rates close to the downlink rates of 60 and 86 kb/s can be achieved.

During packet data communication between an MS and an Internet node, an interworking function (IWF) acts as a gateway, and the layering shown in Fig. 3 is in effect. The Internet's Point-to-Point Protocol (PPP) is used as the link layer. The network layer employs the Internet Protocol (IP).

THIRD-GENERATION WIRELESS SYSTEMS

Many 3G wireless systems are expected to be based on WCDMA technology. Wideband CDMA is being standardized by a consortium of leading standardization organization of the United States, Europe, and Asia, and the resulting standards are being harmonized by the International Telecommunication Union — Radiocommunication Standardization Sector (ITU-R) in its International Mobile Telecommunications in 2000 (IMT-2000) harmonization initiative. We will discuss two leading proposals: cdma2000, which is an extension of IS-95B, and WCDMA, proposed by several European institutions.

CDMA2000

Main parameters of cdma2000 are a) chip rates (Mchips/s) of $N \ge 1.2288$ (N = 1, 3, 6, 9, 12), each corresponding to RF channel bandwidths (MHz) of $N \ge 1.25$; b) 0 or 1 SCC/service at 9.6 kb/s to 2 Mb/s; and c) a frame length of 5, 10, 20, 40, and 80 ms [3].

Several reverse and forward link physical channels are supported. The reverse pilot channel (R-PICH) is an unmodulated spread spectrum signal used to assist the BS in detecting MS transmission. The MS also inserts a reverse power control subchannel in the R-PICH. The reverse power control subchannel is used to transmit forward power control commands. The access channel (R-ACH) is used by the MS to initiate communication with the BS and to respond to paging channel messages. The enhanced access channel (R-EACH) is used by the MS to initiate communication with the BS or



Figure 3. RLP high-speed packet data layering in IS-95B [2].

to respond to an MS-directed message. The reverse common control channel (R-CCCH) is used for the transmission of user and signaling information to the BS when reverse traffic channels are not in use.

The radio configurations (RCs) specify the data rates, channel encoding, and modulation parameters supported on the traffic channel. For spreading rates 1 and 3, there are six RCs for the reverse link and nine RCs for the forward link. RCs 1 and 2 are specified to provide backward compatibility with Telecommunications/Electronics Industries Association (TIA/EIA)-95-B systems. RCs provide different rate sets obtained from the basic rates of 9600 and 14,400 b/s. The reverse traffic channels with RCs 1 and 2 include the reverse fundamental channel (R-FCH) and reverse supplemental code channel (R-SCCH). The reverse traffic channels with radio configurations 3-6 include the reverse dedicated control channel (R-DCCH), R-FCH, and reverse supplemental channel (R-SCH). The R-DCCH and R-FCH are used for the transmission of user and signaling information to the BS during a call. The RSCCH and R-SCH are used for the transmission of user information to the BS during a call. Up to seven R-SCCHs and up to two R-SCHs can be generated for each MS.

The forward pilot channel (F-PICH), transmit diversity pilot channel (F-TDPICH), auxiliary pilot channels (F-APICHs), and auxiliary transmit diversity pilot channels (F-ATD-PICHs) are unmodulated spread spectrum signals used for synchronization by a mobile station operating within the coverage area of the BS. The sync channel (F-SYNCH) is used by MSs operating within the coverage area of the BS to acquire initial time synchronization. The paging channel (F-PCH) is used by the BS to transmit system overhead information and MS-specific messages. The broadcast channel (F-BCH) is used by the BS to transmit system overhead information. The quick paging channel (F-QPCH) is used by the BS to inform MSs. The common power control channel (F-CPCCH) is used by the BS to transmit compower control subchannels mon (1 bit/subchannel) for the power control of multiple reverse common control channels and enhanced access channels. The common assignment channel (F-CACH) is used by the BS to provide quick assignment of the reverse common control channel. The forward common control channel (F-CCCH) is used by the BS to transmit MS-specific messages. For RCs 1 and 2, the forward traffic channels include the forward fundamental channel (F-FCH) and forward supplemental code channel (F-SCCH). For RCs-9, the forward traffic channels include the forward dedicated control channel (F-DCCH), forward fundamental channel (F-FCH), and forward supplemental channel (F-SCH). Up to seven F-SCCHs and up to two F-SCHs are generated.

Different state machines are kept for each active packet or circuit data at the MAC layer. The link access protocol (LAC) sublayer supports highly reliable point-to-point over-the-air transmission of signaling and circuit mode data traffic using automatic repeat request (ARQ) techniques. The logical channel structure of cdma2000 is based on the packet service state transitions. A forward/reverse dedicated MAC logical channel (f/r-dmch control) carries MAC messages. This channel is allocated in active and control hold states. A forward/reverse dedicated traffic logical channel (f/r-dtch) is used to carry user data. It is allocated throughout the active state. A forward/reverse common signaling channel (f/r-csch) and a forward/reverse dedicated signaling channel (f/r-dsch) are used to carry signaling information.

Forward and reverse physical channels may support 5 ms frames, 20 ms frames, or both 5 and 20 ms frames. 5 ms frames are used to carry MAC

Different state machines are kept for each active packet or circuit data at the MAC layer. Link access protocol sublayer supports highly reliable point-to-point over the air transmission of signaling and circuit mode data traffic using automatic repeat request techniques.

Support for high-data-rate transmission, asynchronous base station operation, high service flexibility with support of multiple parallel variable-rate services on each connection and 10 ms frame length, and a chip rate of 3.84 Mc/s are the key features of WCDMA.

messages, whereas 20 ms frames carry upper layer signaling and RLP frames. In the downlink, the forward common logical channels of f-csch are mapped to F-CCCH or F-PCH. The forward link logical channels f-dsch, f-dtch, and f-dmch are mapped to F-FCH. The forward link logical channel f-dtch is mapped to F-SCH, and f-dsch, f-dtch, and f-dmch are mapped to F-DCCH.

The reverse link logical channels r-dsch, rdtch, and r-dmch are mapped to R-FCH; r-dtch can also be mapped to R-SCH or R-DCCH. rdsch and r-dmch are mapped to R-DCCH. The reverse link logical channels r-csch, r-ctch, rcmvch, r-cmsch, and r-cmdch are mapped to R-CCCH or R-ACH.

In order to gain access to one or more of the limited number of traffic channels, MSs use the multiple access channels of R-CCCH or R-ACH to make access probes or packet access requests. A 20 ms frame is divided into 5 ms access probe slots in which a short access request message can be transmitted by an MS. A traffic channel assignment should normally be received during the next frame. Failing that, the MS enters into an exponential backoff procedure in which the access probe is retransmitted after exponentially increasing the number of frame times.

Access probes are made by MSs on R-ACH in order to send either a response to transactions initiated by the BS or channel access requests autonomously. R-ACH is slotted and there is an offset between the slots of different parallel R-ACHs. After an initial backoff, the MS sends a short message called an access probe. If no acknowledgment is received due to a collision, the MS waits for an exponentially increasing backoff period before sending the access probe again.

High-Speed Data Transfer — We take RC 6 on the reverse link and RC 9 on the forward link, which provide 2, 4, 8, 16, 32, and 72 times 14,400 b/s (i.e., with the maximum rate of 1,036,800 b/s) as an example. This maximum rate is possible at spreading rate 3 on a supplementary channel (SCH).

High-speed packet data communication is possible on the links between an MS and the packet data serving node (PDSN), using PPP as the link layer and IP as the network layer. The MS is connected to the BS over the U_m interface. The BS with packet control function (PCF) is connected to the PDSN over the A_{quater} interface. Once a PPP connection is established between the MS and the PDSN, the bandwidth (traffic channels) is allocated to the connection on a dynamic basis.

On the U_m interface the link layer protocol used is RLP type 3 [4], which uses negative acknowledgments to provide a reliable link layer packet mode transfer. Twelve-bit sequence numbers are used, and the packet data is segmented into a maximum of 4096 octet segments, further divided into frames as units of transmission. Each frame can carry up to 256 octets of user data and a 4-octet header. Each 20 ms RLP can receive, at most, 17 RLP frames.

Consider IP datagrams of 1500 octets to be transmitted on a forward link logical channel f-dtch at the rate of 1,036,800 b/s. The PPP layer

adds a header of 8 octets [5]. The resulting packets are transmitted by RLP in several fragments with each frame carrying 256 octets of user data, each fragment to fit into 2592 octets, which is transmitted during one frame of 20 ms. This yields a maximum data rate of 1,020,800 b/s without considering retransmissions. On a reverse link logical channel the same datagram takes at least 20 ms longer to transmit due to multiple access on R-ACH which reduces the maximum data rate. The reverse link rate increases if the MS continues to transmit without waiting for another access procedure while it approaches the rate of the downlink.

WCDMA

Support for high-data-rate transmission (384 kb/s with wide-area coverage, 2 Mb/s with local coverage), asynchronous BS operation, high service flexibility with support of multiple parallel variable-rate services on each connection and a 10 ms frame length, and a chip rate of 3.84 Mchips/s are the key features of WCDMA, which has two versions: frequency-division duplex (FDD) and time-division duplex (TDD). The FDD version is designed to operate in either of the following paired bands:

- 1920–1980MHz: uplink, 2110–2170 MHz: downlink
- 1850–1910 MHz: uplink, 1930–1990MHz: downlink

The European version of IMT-2000, the Universal Mobile Telecommunications System (UMTS), is composed of a core network (CN), connected with interface I_u to the radio access network, called the UMTS Terrestrial Radio Access Network (UTRAN) which is connected to the user equipment (UE) with interface U_{μ} (Fig. 4). The UTRAN consists of a set of radio network subsystems (RNSs) connected to the CN through the I_u . An RNS consists of a radio network controller (RNC) and one or more node Bs. A node B is connected to the RNC through the I_{ub} interface. The RNC is responsible for the handover decisions that require signaling to the UE. Inside UTRAN, the RNCs of the RNSs can be interconnected through the I_{ur} . I_{ur} can be conveyed over a physical direct connection between RNCs or via any suitable transport network. Each RNS is responsible for the resources of its set of cells, and each node B has one or more cells.

Protocol layer 2 of WCDMA is split into the following sublayers: MAC, RLC, Packet Data Convergence Protocol (PDCP), and broadcast/ multicast control (BMC). Layer 3 and RLC are divided into control (C-) and user (U-) planes. PDCP and BMC exist in the U-plane only. In the C-plane, layer 3 is partitioned into sublayers where the lowest sublayer, denoted radio resource control (RRC), interfaces with layer 2 and terminates in the UTRAN. The next sublayer provides "duplication avoidance" functionality, which prevents loss of data in case handovers terminate in the CN. In case of no change to the I_{μ} connection point, the RLC sublayer's ARQ functionality, which is closely coupled with the radio transmission technique used, prevents all loss of data.



Figure 4. 3GPP architecture [6].

Logical/Transport and Physical Channels — The characteristics of a transport channel are defined by its transport format (or format set), specifying the physical layer processing to be applied to the transport channel in question, such as convolutional channel coding and interleaving, and any service-specific rate matching as needed. Random access channel(s) (RACH) (uplink), forward access channel(s) (FACH) (downlink), broadcast channel (BCH) (downlink), paging channel (PCH) (downlink), synchronization channel (SCH) (TDD downlink), downlink shared channel(s) (DSCH), common packet channel (CPCH) (FDD downlink), and uplink shared channel (USCH) (TDD) are common transport channels. The dedicated channel (DCH) (uplink/downlink) and fast uplink signaling channel (FAUSCH) are dedicated transport channels.

Variable bit rate transmission in layer 1 is achieved by associating a transport format or format set to a transport channel. A transport block is a basic unit exchanged between layer 1 and MAC entities and typically corresponds to an RLC PDU. A transport block may be 20 bits of coded speech or 320 bits of RLC PDU. Layer 1 adds cyclic redundancy check (CRC) into a transport block. A transport block is transmitted during a transmission time interval which is 10 ms or a multiple of 10 ms. A set of transport blocks may be transferred during a transmission time interval. The Transport Format Combination Indication field (TFCI) uniquely identifies the transport format used by each transport channel within the current radio frame. The multiplexing and exact rate matching patterns follow predefined rules and are encoded in

TFCI by the transmitter. The receiver derives this information from TFCI without signaling over the radio interface [7].

WCDMA in FDD mode supports several physical channels which transmit the data in the transport channels. Physical channels typically consist of a three-layer structure of superframes, radio frames, and time slots. A superframe has a duration of 720 ms and consists of 72 radio frames. A radio frame has a duration of 10 ms and consists of 15 time slots. Physical channels are the uplink dedicated physical data channel (uplink DPDCH) and uplink dedicated physical control channel (uplink DPCCH). The uplink DPDCH is used to carry dedicated data generated at layer 2 and above (i.e., the dedicated transport channel, DCH). The uplink DPCCH is used to carry control information (pilot symbols, power control commands, TFCI) generated at layer 1. The physical random access channel (PRACH) is used to carry the RACH. The physical common packet channel (PCPCH) is used to carry the CPCH. There is only one type of downlink dedicated physical channel, the downlink dedicated physical channel (downlink DPCH). The primary common pilot channel (CPICH) serves as the phase reference; the primary common control physical channel (P-CCPCH) is used to carry the BCH. The secondary CCPCH is used to carry the FACH and PCH. The SCH is a downlink signal used for cell search. The physical downlink shared channel (PDSCH), used to carry the downlink shared channel (DSCH), is shared by users based on code multiplexing. Depending on the symbol rate of the physical channel, the configuration of radio frames or time slots varies,

Cellular networks have built-in support for mobility in terms of registration, VLR/HLR, and handover procedures. The problem arises for incoming datagrams from the Internet which are routed according to the destination IP address.



Figure 5. Mobile IP in cdma2000 [9].

The random access transmission is based on a Slotted ALOHA approach with fast acquisition indication. UE can start transmitting at access slots where there are 15 access slots per two frames. The random access transmission consists of one or several preambles of length 4096 chips, and a message of length 10 ms. The message has a data part to transmit layer 2 data, and a control part to transmit pilot bits and TFCI. The data and control parts are transmitted in parallel. The highest RACH data transmission rate is 120 kb/s.

The MAC layer provides data transfer services on logical channels which are divided into control channels (for the transfer of control plane information) and traffic channels (for the transfer of user plane information). The synchronization control channel (SCCH), broadcast control channel (BCCH), paging control channel (PCCH), common control channel (CCCH), dedicated control channel (DCCH), and shared channel control channel (SHCCH) are the control channels. A dedicated traffic channel (DTCH) is a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink; it is a point-to-multipoint unidirectional channel for transfer of dedicated user information for all or a group of specified UEs.

High-Speed Data Transfer — The RLC layer performs segmentation/reassembly of variablelength higher-layer PDUs into/from smaller RLC payload units (PUs). The RLC PDU size is adjustable to the actual set of transport formats. RLC transfers user data, and the transfer may be unacknowledged on the control plane logical channels of BCCH, PCCH, CCCH, SHCCH, and SCCH (downlink only) and on the U-plane logical channel of DTCH, or reliable delivery with flow control on DCCH/DTCH logical channels. CCCH uses unacknowledged mode (segmentation/reassembly with sequence number checking), but only for the downlink, and transparent mode (only segmentation/ reassembly is performed) only for the uplink. 320-bit frames are used for segmentation/ reassembly. In acknowledged mode the first two octets contain the header fields such as 12-bit sequence number, and the rest is used for user data. In order to transmit at higher rates, the header compression procedure enables placing four 80-bit PUs with only the first PU having a header.

In WCDMA each slot carries 2560 chips. At a spreading factor of 4, each slot carries 640 bits and, with 15 slots in 10 ms, yields an uplink bit rate of 960 kb/s. The downlink rate is twice the uplink bit rate because the symbol bit rate is half the channel bit rate. If burst type 1 is used, each slot can carry 488 data bits, which yields a data bit rate of 732 kb/s for the uplink and 1464 kb/s for the downlink. Higher rates can be obtained if multiple codes are used.

Consider IP datagrams of 1500 octets to be transmitted on the uplink. The RLC layer segments the datagram into 27 RLC PDUs and adds a 2-octet header into each. The MAC layer adds a 3-octet header if 16-bit UE-id fields are used and forms MAC PDUs. Each such PDU can be transmitted in one slot. This yields an uplink data rate of 672 kb/s. The downlink data rate is 1344 kb/s.

INTEGRATION WITH THE INTERNET

Efficient support of Mobile IP in wireless networks is important for the integration of wireless networks with the Internet.

In the wired Internet, when a node moves from one network to another, Mobile IP [8] is used to correctly deliver the datagrams into the new network. Operation of Mobile IP is as follows. A



Figure 6. Mobile IP in 3GPP [9].

router called the *home agent* (HA) in the home network tunnels the datagrams to either another router, the *foreign agent* (FA), in the visited network or directly to the mobile host. The new location of the mobile host is made known to the HA using registration signaling. The HA and FA send periodic agent advertisements. The mobile sends a registration request to the FA which is relayed to the HA. Registration terminates with a registration reply sent to the mobile by the FA.

Cellular networks have built-in support for mobility in terms of registration, VLR/HLR, and handover procedures. The problem arises for incoming datagrams from the Internet which are routed according to the destination IP address. These datagrams will arrive at the BS in the home cell of the MS. If the MS is not at its home cell, Mobile IP support is needed in order to route the datagrams to the destination cell. Supporting Mobile IP requires HA and FA functionality in the cellular network infrastructure (PDSN, SGSN, GGSN, etc.).

Integration of Mobile IP in cdma2000 is based on the PDSN supporting Mobile IP FA functionality (Fig. 5). The PDSN is connected to the radio network via an R-P interface. A link layer connection is established between the MS and the PDSN after the MS connects to the CDMA network using PPP. After PPP initialization, the PDSN sends agent advertisements to the MS. The MS generates a Mobile IP registration request, and the PDSN sends this to the HA using an authentication, authorization, and accounting (AAA) protocol. The PDSN extracts the Mobile IP registration reply from the HA and forwards it to the MS.

Handoff between the RN within the same PDSN is handled by transferring the existing R-P link to the new RN and terminating the endpoint with the old RN. In case of handoff between PDSNs, the traffic channel is transferred to the new RN, and a new packet service session ID is created between the new RN and new PDSN, and the packet endpoint to the old PDSN is closed. Using the session ID, the PDSN realizes that this is a new R-P link and not an existing link. If Mobile IP route optimization is supported, binding update messages are sent to the corresponding hosts, and the corresponding hosts start to tunnel their datagrams to the new PDSN.

The Third Generation Partnership Project (3GPP) approach to integrating Mobile IP is based on CN nodes called *Internet GPRS support* nodes (IGSNs) to provide FA functionality with commonly deployed extensions such as identifying clients by using network access identifiers (NAIs). During PPP session establishment, the MS gets a care-of address (temporary IP address) from the IGSN and uses this address instead of its home IP address (Fig. 6).

The MS first performs the International Mobile Subscriber Identity (IMSI) attach and PDP context setup procedures which establish a link layer connection to start using 3GPP services for packet data. Over this connection the IGSN sends an agent advertisement message; the MS gets its care-of address and then registers with its HA. The HA intercepts the datagrams arriving in the home network and tunnels them to the careof address, in this case the FA (IGSN). Before the IGSN can deliver the datagram to the mobile node, paging and other functions need to be performed according to general UMTS/GPRS procedures. During handoff, the MS may go to an area served by a different IGSN; then the MS, after establishing a link layer connection with the new IGSN, goes through a new Mobile IP registration process. After registering its new care-of address with the HA, the HA tunnels the datagrams from correspondent hosts to the new IGSN, which delivers them to the MS.

The model shown in Fig. 6 assumes that the CN has native Mobile IP support. The IGSN nodes support route optimization in which the correspondent nodes are notified of the new

The 3GPP approach to integrating Mobile IP is based on core network nodes called Internet GPRS support nodes to provide FA functionality with commonly deployed extensions such as identifying clients by using network access identifiers.

It seems to be a challenge to reach a world-wide consensus on a standard for 3G wireless network. Similarities on cdma2000 and WCDMA approaches indicate that such a consensus can be reached. care-of address of the MS, and the correspondent nodes start tunneling the datagrams to the MS directly at its new care-of address.

CONCLUSIONS

Present cellular systems are based on TDMA and CDMA technologies, and provide packet data transmission at low rates. We present 2G+ systems GSM GPRS and IS-95B. GPRS is a TDMA- and IS-95B a CDMA-based system. Packet mode data capabilities of these networks represent several improvements over 2G cellular networks.

Wideband CDMA is presently accepted as the technology for third-generation cellular networks. We discuss two proposals: cdma2000 and WCDMA. Both standards offer higher packet data rates and facilitate interconnection with the Internet.

It seems a challenge to reach world-wide consensus on a standard for 3G wireless network. Similarities in the cdma2000 and WCDMA approaches indicate that such a consensus can be reached.

REFERENCES

[1] ETSI, "General Packet Radio Service (GPRS); Mobile Station (MS)-Base Station System (BSS) Interface; Radio Link Control/Medium Access Control (RLC/MAC) Protocol (GSM 04.60)," tech. spec. V8.1, Sophia Antipolis, France, Nov. 1999.

- [2] TIA/EIA, "Data Services Option Standard for Spread Spectrum Systems: High Speed Packet Data Services," IS-707.9, July 1998.
- [3] TIA/EIA, "Physical Layer Standard for cdma2000 Spread Spectrum Systems," IS-2000-2, Aug, 1999.
- [4] TIA/EIA, "Data Service Options for Spread Spectrum Systems: Radio Link Protocol Type 3," IS-707.A.1 (3GPP2/C.S0017-0-2.10), Jan. 2000.
- [5] W. Simpson, "The Point to Point Protocol (PPP)." IETF RFC 1661, July 1994.
- [6] 3GPP, "Stage 2 Functional Specification of Location Services in UTRAN," 3G TS 25.305, Dec. 1999.
- [7] 3GPP, "Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD)," 3G TS 25.211, Oct. 1999.
- [8] C. Perkins, "IP Mobility Support," IETF RFC 2002, Oct. 1996. [9] TIA/EIA, "Wireless IP Network Architecture based on
- IETF Protocols," PN-4286, Feb. 2000. [10] 3GPP, "Combined GSM and MobileIP Mobility Handling in UMTS IP CN," 3G TS 23.923, Oct. 1999.

BIOGRAPHY

BEHCET SARIKAYA [SM] (sarikaya@u-aizu.ac.jp) obtained his Ph.D. in computer science from McGill University's School of Computer Science in 1984. He worked at Universite de Sherbrooke (1984–1985) and Concordia University (1985-1990) as assistant professor, Universite de Montreal (1990–1991) as visiting professor, Bilkent University, Ankara, Turkey (1991–1993) as associate professor, and University of Aizu, Japan (1993-present) as professor. His research interests lie in personal communication systems, mobile computing and multimedia in PCS. He has had several publications on multimedia networking; in his recent publications he is concentrating on cellular networks, multimedia communication in cellular networks, and integration of cellular networks with the Internet. He serves on the editorial board of Cluster Computing Journal published by Baltzer Science.