In This Issue:
1994 RCA Banquet Coverage – Pg. 4
August J. Link Preserves Radio History – Pg. 15
Bandwidth-Efficient Technology – Pg. 18
Commander Albert Hoyt Taylor – Pg. 28
Tutorial on GSM – Pg. 36
A Tutorial on Global System for Mobile Communications (GSM)

By Theodore S. Rappaport, Rias Muhamed and Kevin J. Saldanha

Abstract: GSM quickly is emerging as the leading cellular radio standard throughout the world. With the advent of new personal communications frequencies in the 1.8 - 2 GHz band, GSM and its PCS offshoot, DCS, may be implemented in North America within the next 12 months to 18 months. This tutorial is part of an independent learning program prepared by the authors for the IEEE. This material is taught as part of an introductory course on wireless communications at Virginia Tech and will be included in the textbook Wireless Communications: Principles and Practice published by Prentice-Hall.

Global System for Mobile Communications

Global system for mobile communications (GSM) is a second-generation cellular system standard that was developed to solve the fragmentation problems of the first cellular systems in Europe [Mou92]. Unlike the U.S. cellular carriers which implemented the first-generation analog mobile phone system (AMPS) throughout the country, the first-generation cellular service providers in Europe took a provincial view of cellular.

Before GSM, European countries used different cellular standards throughout the continent, and it was not possible for a customer to use a single mobile phone throughout Europe.

After five years and hundreds of person-years of engineering, the European community developed an amazingly robust and complex cellular standard that was first to specify digital modulation and network level architectures and service.

GSM originally was developed to serve just the pan-European cellular market and promised a wide range of network services through the use of integrated services digital network (ISDN). However, during the past two years, GSM's success has exceeded the expectations of virtually everyone, and it is now the world's most popular standard for new cellular radio and personal communications equipment throughout the world.

It is predicted that by the year 2000, there will be between 20 million and 50 million GSM subscribers worldwide [Mou92], [Dec93]. The task of specifying a common mobile communication system for Europe in the 900 MHz band was taken up by the GSM (Groupe special mobile) committee, which was a working group of the Conference of European Postes des et Teledécommunication (CEPT). The setting of standards for GSM is currently under the aegis of the European Technical Standards Institute (ETSI).

GSM first was introduced into the European market in 1991. By the end of 1993, several non-European countries in South America, Asia and Australia had adopted GSM and the technically equivalent offshoot, DCS 1800, which supports personal communication services (PCS) in the 1.8-2.0 GHz radio bands recently created by governments throughout the world.

GSM Services, Features

GSM services follow ISDN guidelines and are classified as either teleservices or data services. Teleservices include standard mobile telephony and mobile-originated or base-originated traffic. Data services include computer-to-computer communication and packet-
switched traffic. User services may be divided into
three major categories:

Telephone services, including emergency calling and facsimile. GSM also supports Videotex and Teletex, though they are not integral parts of the GSM standard.

Bearer services or data services, which are limited to layers 1, 2 and 3 of the open system interconnection (OSI) reference model. Supported services include packet-switched protocols and data rates from 300 bps to 9.6 kbps. Data may be transmitted using either a transparent mode (where GSM provides standard channel coding for the user data) or non-transparent mode (where GSM offers special coding efficiencies based on the particular data interface).

Supplementary ISDN services, including call diversion, closed user groups and caller identification. These services are not available in analog mobile networks. Supplementary services also include the short messaging service (SMS), which allows GSM subscribers and base stations to transmit alphanumeric pages of limited length (160 7-bit ASCII characters) while simultaneously carrying normal voice traffic. SMS provides cell broadcast, which allows GSM base stations to repetitively transmit ASCII messages with as many as fifteen 93-character strings in concatenated fashion. SMS may be used for safety and advisory applications, such as the broadcast of highway or weather information to all GSM subscribers within reception range.

From the user's point of view, one of the most remarkable features of GSM is the subscriber identity module (SIM), which is a memory device that stores information such as the subscriber's identification number, the networks and countries where the subscriber is entitled to service, privacy keys and other user-specific information. A subscriber uses the SIM with a four-digit personal ID number to activate service from any GSM phone.

SIMs are available as smart cards (credit-card-sized cards that may be inserted into any GSM phone) or plug-in modules, which are less convenient than the SIM cards but are nonetheless removable and portable. Without a SIM installed, all GSM mobiles are identical and non-operational. It is the SIM that gives GSM subscriber units their identities. Subscribers may plug their SIM into any suitable terminal—such as a hotel phone, public phone, or any portable or mobile phone—and then are able to have all incoming GSM calls routed to that terminal and have all outgoing calls billed to their home phone, no matter where they are in the world.

A second remarkable feature of GSM incorporates the on-the-air privacy, which is provided by the system. Unlike analog FM cellular phone systems which can be readily monitored, it is virtually impossible to eavesdrop on a GSM radio transmission.

The privacy is made possible by encrypting the digital bit stream sent by a GSM transmitter, according to a specific secret cryptographic key that is known only to the cellular carrier. This key changes with time for each user. Every carrier and GSM equipment manufacturer must sign the memorandum of understanding (MoU) before developing GSM equipment or deploying a GSM system. The MoU is an international agreement that allows the sharing of cryptographic algorithms and other proprietary information between countries and carriers.

GSM System Architecture

The GSM system architecture consists of three major interconnected subsystems that interact between themselves and with the users through certain network interfaces. The subsystems are the base station subsystem (BSS), network and switching subsystem (NSS) and the operation support subsystem (OSS). The mobile station (MS) is also a subsystem, but it is usually considered to be part of the BSS for architecture purposes.

Equipment and services are designed within GSM to support one or more of these specific subsystems. The BSS, also known as the radio subsystem, provides and manages radio transmission paths between the mobile stations and the mobile switching center (MSC). The BSS also manages the radio interface between the mobile stations and all other GSM subsystems.

Each BSS consists of many base station controllers (BSCs), which connect the MS to the NSS via the MSCs. The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the public switched telephone network (PSTN) and ISDN.

The OSS supports the operation and maintenance of GSM and allows system engineers to monitor, diagnose and troubleshoot all aspects of the GSM system. This subsystem interacts with the other GSM subsystems and is provided solely for the staff of the GSM operating company, which provides service facilities for the network.

Figure 1 shows the block diagram of the GSM system architecture. The mobile stations communicate with the BSS over the radio air interface. The BSS consists of many BSCs that connect to a
single MSC, and each BSC typically controls as many as several hundred base transceiver stations (BTSs).

Some BTSs may be co-located at the BSC, and others may be remotely distributed and physically connected to the BSC by microwave link or dedicated leased lines.

Mobile handoffs (called handovers, or HO, in the GSM specification) between two BTSs under the control of the same BSC are handled by the BSC, and not the MSC. This greatly reduces the MSC’s switching burden.

As shown in Figure 2, the interface that connects a BTS to a BSC is called the Abis interface. The Abis interface carries traffic and maintenance data and is specified by GSM to be standardized for all manufacturers. In practice, however, the Abis for each GSM base station manufacturer has subtle differences, thereby forcing service providers to use the same manufacturer for the BTS and BSC equipment.

The BSCs are connected physically via dedicated/leased lines or microwave link to the MSC. The interface between a BSC and a MSC is called the A interface, which is standardized within GSM. The A interface uses an SS7 protocol called the signaling correction control part (SCCP), which supports communication between the MSC and the BSS, as well as network messages between the individual subscribers and the MSC. The A interface allows a service provider to use base stations and switching equipment made by different manufacturers.

The NSS handles the switching of GSM calls between external networks and the BSCs in the radio subsystem and is also responsible for managing and providing external access to several customer databases. The MSC is the central unit in the NSS and controls the traffic among all of the BSCs.

In the NSS, there are three different databases called the home location register (HLR), visitor location register (VLR) and the authentication center (AUC).

The HLR is a database that contains subscriber information and location information for each user who resides in the same city as the MSC. Each subscriber in a particular GSM market is assigned a unique international mobile subscriber identity (IMSI), and this number is used to identify each home user.

The VLR is a database that temporarily stores the IMSI and customer information for each roaming subscriber who is visiting the coverage area of a particular MSC. The VLR is linked between several adjoining MSCs in a particular market or geographic region and contains subscription information of every visiting user in the area. Once a roaming mobile is logged in the VLR, the MSC sends the necessary information to the visiting subscriber’s HLR so that calls to the roaming mobile can be appropriately routed over the PSTN by the roaming user’s HLR.

The authentication center is a strongly protected database that handles the authentication and encryption keys for every single subscriber in the HLR and VLR. The center contains a register called the equipment identity register (EIR), which identifies stolen or fraudulently altered phones that transmit identity data that does not match with information contained in either the HLR or VLR.

The OSS supports one or several operation maintenance centers (OMC), which are used to monitor and maintain the performance of each MS, BS, BSC and MSC within a GSM system. The OSS has three main functions, which are to maintain all telecommunications hardware and network operations with a particular market, manage all charging and billing procedures and manage all mobile equipment in the system.

Within each GSM system, an OMC is dedicated to each of these tasks and has provisions for adjusting all base station parameters and billing procedures, as well as for providing system operators with the ability to determine the performance and integrity of each piece of subscriber equipment in the system.
TDMA. The total number of available channels within a 25 MHz bandwidth is 125 (assuming no guard band).

Since each radio channel consists of eight time slots, there are thus a total of 1,000 traffic channels within GSM. In practical implementations, a guard band of 100 kHz is provided at the upper and lower end of the GSM spectrum, and only 124 channels are implemented.

The combination of a TS number and an ARFCN constitutes a physical channel for both the forward and reverse link. Each physical channel in a GSM system can be mapped into different logical channels at different times. That is, each specific time slot or frame may be dedicated to either handling traffic data (user data such as speech, facsimile or teletext data), signaling data (required by the internal workings of the GSM system) or control channel data (from the MSC, base station or mobile user). The GSM specification defines a wide variety of logical channels that can be used to link the physical layer with the data link layer of the GSM network. These logical channels efficiently transmit user data while simultaneously providing control of the network on each ARFCN. GSM provides explicit assignments of time slots and frames for specific logical channels, as described below.

GSM Channel Types

Channel Types: There are two types of GSM logical channels, called traffic channels (TCH) and control channels (CCH) (Hodg90). Traffic channels carry digitally encoded user speech or user data and have identical functions and formats on both the forward and reverse link. Control channels carry signaling and synchronizing commands between the base station and the mobile station.

Certain types of control channels are defined for just the forward or reverse link. There are six different types of TCHs provided for in GSM, and an even larger number of CCHs, which are described next.

GSM Traffic Channels (TCH)

GSM traffic channels may be either full rate or half rate and may carry either digitized speech or user data. When transmitted as full rate, user data is contained within one TS per frame. When transmitted as half rate, user data is mapped onto the same time slot but is sent in alternate frames. That is, two half-rate channel users would share the same time slot but would alternately transmit during every other frame.
In the GSM standard, TCH data may not be sent in TS 0 within a TDMA frame on certain ARFCNs that serve as the broadcast station for each cell (since this time slot is reserved for control channel bursts in most every frame, as described subsequently). Furthermore, TCH data frames are broken up every 13th frame by either slow associated control channel data (SACCH) or idle frames.

Figure 3 illustrates how the TCH data is transmitted in consecutive frames. Each group of 26 consecutive TDMA frames is called a multiframe (or speech multiframe, to distinguish it from the control channel multiframe described below). For every 26 frames, the 13th and 26th frames consist of slow associated control channel (SACCH) data, or the idle frame, respectively. The 26th frame contains idle bits for the case when full-rate TCHs are used and contains SACCH data when half-rate TCHs are used. In GSM, fast associated control channel (FACCH) data may be sent in place of user data at any time.

![Figure 3. The Speech Dedicated Control Channel Frame and Multiframe structure](image)

**GSM Control Channels (CCH)**

There are three main control channels in the GSM system. These are the broadcast channel (BCH), the common control channel (CCCH) and the dedicated control channel (DCCH). Each control channel consists of several logical channels that are distributed in time to provide the necessary GSM control functions.

The BCH and CCCH forward control channels in GSM are implemented only on certain ARFCN channels and are allocated time slots in a very specific manner. Specifically, the BCH and CCCH forward control channels are allocated only TS 0 and are broadcast only during certain frames within a repetitive 51 frame sequence (called the control channel multiframe) on those ARFCNs that are designated as broadcast channels. TS 1 through TS 7 carry regular TCH traffic, so that ARFCNs that are designated as control channels still are able to carry full-rate users on seven of the eight time slots.

The GSM specification defines 34 ARFCNs as standard broadcast channels. For each broadcast channel, frame 51 does not contain any BCH/CCCH forward-channel data and is considered to be an idle frame. However, the reverse channel CCCH is able to receive subscriber transmissions during TS 0 of any frame (even the idle frame). On the other hand, DCCH data may be sent during any time slot and any frame, and entire frames are dedicated specifically to certain DCCH transmissions.

On the BCH channel, synchronization and frequency correction data are sent to each mobile on the forward link using broadcast control channel (BCCH), frequency correction channel (FCCH) and synchronization channel (SCH).

The CCCH provides common control channels on both forward and reverse links. On the reverse link, the mobile responds to a call or requests service via a random access control channel (RACH). The base station broadcasts paging messages to all mobiles on the paging channel (PCH).

The DCCH provides dedicated slow and fast control signaling to calls as they are initiated. In particular, the slow dedicated control channel (SDCCH) is used to carry data following the connection of the mobile with the base station, and just before a TCH assignment is issued by the base station. The SDCCH ensures that the mobile station and the base station remain connected while the MSC verifies the subscriber unit and allocates resources for the call.

**How a GSM Call Is Made**

To understand how the various traffic and control channels are used, consider the case of a mobile call origination in GSM. First, the subscriber unit must be synchronized to a nearby base station as it monitors the BCH. By receiving the FCCH, SCH and BCCH messages, the subscriber would be locked on to the system and the appropriate BCH.

To originate a call, the user first dials the desired digits and presses the "send" button on the GSM phone. The mobile transmits a burst of RACH data, using the same ARFCN as the base station to which it is locked. The base station then responds with an AGCH message on the CCCH, which assigns the mobile unit to a new channel for SDDCH
connection.

The subscriber unit, which is monitoring TS 0 of the BCH, would receive its ARFCN and TS assignment from the AGCH and would tune immediately to the new ARFCN and TS. This new ARFCN and TS assignment is physically the SDCCH (not the TCH).

Once tuned to the SDCCH, the subscriber unit first waits for the SAACH frame to be transmitted (the wait would last, at most, 26 frames or 120 ms, as shown in Figure 3), which informs the mobile of any required timing advance and transmitter power command. The base station is able to determine the proper timing advance and signal level from the mobile’s earlier RACH transmission and sends the proper value over the SAACH for the mobile to process.

Upon receiving and processing the timing advance information in the SAACH, the subscriber now is able to transmit normal burst messages as required for speech traffic. The SDCCH sends messages between the mobile unit and the base station, taking care of authentication and user validation, while the PSTN connects the dialed party to the MSC, and the MSC switches the speech path to the serving base station.

After a few seconds, the mobile unit is commanded by the base station via the SDCCH to return to a new ARFCN and new TS for the TCH assignment. Once retuned to the TCH, speech data is transferred on both the forward and reverse links, the call is successfully under way, and the SDCCH is vacated.

When calls are originated from the PSTN, the process is quite similar. The base station broadcasts a PCH message during TS 0 within an appropriate frame on the BCH. The mobile station, locked on to that same ARFCN, detects its page and replies with an RACH message acknowledging receipt of the page. The base station then uses the AGCH on the CCCH to assign the mobile unit to a new physical channel for connection to the SDCCH and SAACH while the network and the serving base station are connected.

Once the subscriber establishes timing advance and authentication on the SDCCH, the base station issues a new physical channel assignment over the SDCCH, and the TCH assignment is made.

**Frame Structure for GSM**

Figure 4 illustrates the data structure within a normal burst. It consists of 148 bits, which are transmitted at a rate of 270.833333 kbps (an unused guard time of 8.25 bits is provided at the end of each burst). Out of the total 148 bits per TS, 114 are information-bearing bits that are transmitted as two 57-bit sequences close to the beginning and end of the burst.

The midamble consists of a 26-bit training sequence that allows the adaptive equalizer in the mobile or base station receiver to analyze the radio channel characteristics before decoding the user data. On either side of the midamble, there are control bits called stealing flags. These two flags are used to distinguish whether the TS contains voice (TCH) or control (FAACH) data, both which share the same physical channel.

During a frame, a GSM subscriber unit uses one TS to transmit, one TS to receive, and may use the six spare time slots to measure signal strength on five adjacent base stations as well as its own base station.

As shown in Figure 4, there are eight time slots per TDMA frame, and the frame period is 4.615 ms. A frame contains 8X156.25=1,250 bits, although some bit periods are not used. The frame rate is 270.833 kbps/1,250 bits/frame, or 216.66 frames per second. The 13th or 26th frame are not used for traffic, but for control purposes. Each of the normal speech frames is grouped into larger structures called multiframes, which in turn are grouped into superframes and hyperframes (hyperframes are not shown in Figure 4).

One multiframe contains 26 TDMA frames, and one superframe contains 51 multiframes, or 1,326 TDMA frames. A hyperframe contains 2,048 superframes, or 2,715,648 TDMA frames. A complete hyperframe is sent about every three hours, 28 minutes and 54 seconds and is important to GSM since the encryption algorithms rely on the particular frame number, and sufficient security only can be obtained by using a large number of frames as provided by the hyperframe.

![GSM Frame Structure](image-url)
Signal processing in GSM

Figure 5 illustrates all of the GSM operations from transmitter to receiver.

Speech Coding: The GSM speech coder is based on the residually excited linear predictive coder (RELP), which is enhanced by including a long-term predictor (LTP) [Hel89]. The coder provides 260 bits for each 20 ms blocks of speech, which yields a bit rate of 13 kbps. This speech coder was selected after extensive subjective evaluation of various candidate coders available in the late 1980s. Provisions for incorporating half-rate coders are included in the specifications.

The GSM speech coder takes advantage of the fact that in a normal conversation, each person speaks on average for less than 40 percent of the time. By incorporating a voice activity detector (VAD) in the speech coder, GSM systems operate in a discontinuous transmission mode (DTX), which provides a longer subscriber battery life and reduces instantaneous radio interference since the GSM transmitter is not active during silent periods. A comfort noise subsystem (CNS) at the receiving end introduces a background acoustic noise to compensate for the annoying switched muting, which occurs due to DTX.

TCH/FS, SACCH and FACCH Channel Coding: The output bits of the speech coder are ordered into groups for error protection, based upon their significance in contributing to speech quality. Out of the total 260 bits in a frame, the most important 50 bits called type Ia bits have 3 parity check (CRC) bits added to them. This facilitates the detection of uncorrectable errors at the receiver. The next 132 bits along with the first 53 (50 type Ia bits + 3 parity bits) are reordered and appended by 4 trailing zero bits, thus providing a data block of 189 bits. This block then is encoded for error protection using a rate 1/2 convolutional encoder with constraint length \( K = 5 \), thus providing a sequence of 378 bits.

The least important 78 bits do not have any error protection and are concatenated to the existing sequence to form a block of 456 bits in a 20 ms frame. The error protection coding scheme increases the gross data rate of the GSM speech signal, with channel coding, to 22.8 kbps.

Channel Coding for Data Channels: The coding provided for GSM full-rate data channels (TCH/F9.6) is based on handling 60 bits of user data at 5ms intervals, in accordance with the modified CCITT V.110 modem standard. As described in Chapter 8 of Ste92, 240 bits of user data are applied with 4 tailing bits to a half-rate punctured convolutional coder with constraint length \( K = 5 \).

The resulting 488 coded bits are reduced to 456 encoded data bits through puncturing (32 bits are not transmitted), and the data is separated into four 114-bit data bursts that are applied in an interleaved fashion to consecutive time slots.

Channel Coding for Control Channels: GSM control channel messages are defined to be 184-bits long and are encoded using a shortened binary cyclic fire code, followed by a half-rate convolutional coder.

The fire code uses the generator polynomial,

\[
G_0(x) = (x^{23} + 1)(x^{17} + x^3 + 1) = x^{40} + x^{26} + x^{23} + x^{17} + x^3 + 1
\]

which produces 184-message bits, followed by 40 parity bits. Four tail bits are added to clear the convolutional coder that follows, yielding a 228 bit data block. This block is applied to a half-rate \( K = 5 \) convolutional code (CC(2,1,5) using the generator polynomials \( G_0(x) = 1 + x^3 + x^4 \) and \( G_1(x) = 1 + x + x^3 + x^4 \) (which are the same polynomials used to encode TCH type Ia data bits). The resulting 456 encoded bits are interleaved onto eight consecutive frames in the same manner as TCH speech data.
Interleaving: In order to minimize the effect of sudden fades on the received data, the total of 456 encoded bits within each 20ms speech frame or control message frame are broken into eight 57 bit sub-blocks. These eight sub-blocks, which make up a single speech frame, are spread over eight consecutive TCH time slots. (i.e. eight consecutive frames for a specific TS).

If a burst is lost due to interference or fading, channel coding ensures that enough bits still will be received correctly to allow the error correction to work. Each TCH time slot carries two 57-bit blocks of data from two different 20 ms (456 bit) speech (or control) segments.

Figure 7 illustrates exactly how the speech frames are diagonally interleaved within the time slots. Note that TS 0 contains 57 bits of data from the 0th sub-block of the nth speech coder frame (denoted as "a" in the figure) and 57 bits of data from the 4th sub-block of the (n-1) st speech coder frame (denoted as "b" in the figure).

Ciphering: Ciphering modifies the contents of the eight interleaved blocks through the use of encryption techniques known only to the particular mobile station and base transceiver station. Security is further enhanced by the fact that the encryption algorithm is changed from call to call.

Two types of ciphering algorithms, called A3 and A5, are used in GSM to prevent unauthorized network access, and privacy for the radio transmission, respectively. The A3 algorithm is used to authenticate each mobile by verifying the user's passcode within the SIM with the cryptographic key at the MSC. The A5 algorithm provides the scrambling for the 114 coded data bits sent in each TS.

Burst Formatting: Burst formatting adds binary data to the ciphered blocks, in order to help synchronization and equalization of the received signal.

Modulation: The modulation scheme used by GSM is 0.3 GMSK, where 0.3 describes the 3dB bandwidth of the Gaussian pulse shaping filter with relation to the bit rate (e.g. BT = 0.3). GMSK is a special type of digital FM modulation. Binary ones and zeros are represented in GSM by shifting the RF carrier by +/-67.708 kHz.

The channel data rate of GSM is 270.833333 kbps, which is exactly four times the RF frequency shift. This minimizes the bandwidth occupied by the modulation spectrum and hence improves channel capacity. The MSK modulated signal is passed through a Gaussian filter to smooth the rapid frequency transitions that would otherwise spread energy into adjacent channels.

Frequency Hopping: Under normal conditions, each data burst belonging to a particular physical channel is transmitted using the same carrier frequency. However, if users in a particular cell have severe multipath problems, the cell may be defined as a hopping cell by the network operator, in which case slow frequency hopping may be implemented to combat the multipath or interference effects in that cell.

Frequency hopping is carried out on a frame by frame basis, thus hopping occurs at a maximum rate of 217.6 hops per second. As many as 64 different channels may be used before a hopping sequence is repeated. Frequency hopping is completely specified by the service provider.

Equalization: Equalization is performed at the receiver with the help of the training sequences transmitted in the midamble of every time slot. The type of equalizer for GSM is not specified and is left up to the manufacturer.

Demodulation: The portion of the transmitted forward channel signal, which is of interest to a particular user, is determined by the assigned TS and ARFCN. The appropriate TS is demodulated with the aid of synchronization data provided by the burst formatting. After demodulation, the binary information is deciphered, de-interleaved, channel decoded and speech decoded.
The GSM standard is the world's first digital cellular communications standard and offers unprecedented network services for its users. Already with a four-year track record in Europe, GSM is poised for leadership in new personal communications systems being built throughout the world.

This paper has attempted to boil down the GSM standard from 15 large volumes into a tutorial that is less intimidating. As service providers strive to offer new wireless services with minimal risk and quickest time to market, we are likely to see GSM deployed in some of the new U.S. PCS systems that were licensed earlier this year.

### References


Dr. Theodore S. Rappaport is an RCA Fellow and an active researcher, educator and consultant in the field of wireless communications. He is a professor of electrical engineering and founder of the Mobile and Portable Radio Research Group at Virginia Tech, Blacksburg, VA.

Rias Muhamed is a graduate student in the Mobile and Portable Radio Research Group at Virginia Tech. He has co-authored chapters for the “CRC Engineering Handbook on Mobile and Cellular Radio Communications” as well as on Propagation Models. His M.S. thesis work is on adaptive antennas for mobile communications.