Abstract
This tutorial paper provides an overview of the fundamental concepts used in cellular radio communications, and illustrates the likely evolution and growth of the personal communications field. This paper also summarizes some of the most popular wireless standards used throughout the world, and has been adapted from [1].

1. Evolution of Mobile Radio Communications
The ability to communicate with people on the move has evolved remarkably since Guglielmo Marconi first demonstrated radio's ability to provide continuous contact with ships sailing the English channel. That was in 1898, and since then, new wireless communications methods and services have been embraced by citizens throughout the world. Particularly during the past ten years, the mobile radio communications industry has grown by orders of magnitude, fueled by digital and RF circuit fabrication improvements, new large-scale circuit integration and other miniaturization technologies which make portable radio equipment smaller, cheaper, and more reliable. Digital switching techniques have facilitated the large scale deployment of affordable, easy-to-use radio communication networks. This trend will continue at an even greater pace during the next decade.

Wireless communications is enjoying its fastest growth period in history, due to enabling technologies which permit miniaturization, digital signal processing, networking, and switching. Historically, growth in the mobile communications field came slowly, and in the past was coupled closely to technological improvements which did not come about easily. The ability to provide wireless communications to an entire population was not even conceived until Bell Laboratories developed the cellular concept in the 1960's and 1970's [2], [3], [4]. With the development of highly reliable, miniature, solid-state radio frequency hardware in the 1970's, the wireless communications era was born. The recent explosion in cellular radio and personal communication systems throughout the world is directly attributable to new technologies of the 1970's, which are mature today. The future growth of consumer-based mobile and portable communication systems will be tied more closely to radio spectrum allocations and regulatory decisions which affect or support new or extended services, as well as to technology advances in the signal processing, access, and network areas.

The following market penetration data show how wireless communications in the consumer sector has grown during the past several decades. Figure 1 illustrates how mobile telephone has penetrated our daily lives compared with other popular inventions of the 20th century. Figure 1 is a bit understated, since it does not consider non-telephone mobile radio usage, such as paging, amateur radio, dispatch, citizens band (CB), public service, cordless phones, or terrestrial microwave radio systems. In fact, in late 1990, licensed non-cellular radio systems in the U.S. had over 12 million users, more than twice the U.S. cellular user population at that time [5]. Figure 1 shows that the first 35 years of mobile telephone saw little market penetration due to high cost and the technological challenges involved, and illustrates how in the past decade, cellular telephone has been accepted by consumers at rates which are comparable to the television, the video cassette recorder (VCR), and cable television.

2. Examples of Mobile Radio Systems
Mobile radio transmission systems may be classified as simplex, half-duplex or full-duplex. In simplex systems, communication is possible in only one direction. Paging systems, in which messages are received but not acknowledged, are simplex systems. Half-duplex radio systems allow two-way communication, but use the same radio channel for both transmission and reception. This means that
at any given time, a user can only transmit or receive information. Constraints like 'push-to-talk' and 'release-to-listen' are fundamental features of half-duplex systems. Full duplex systems, on the other hand, allow simultaneous radio transmission and reception between a subscriber and a base station, by providing two simultaneous but separate channels (Frequency Division Duplex, or FDD) or adjacent time slots on a single radio channel (Time Division Duplex, or TDD) for communication to and from the user.

Frequency division duplexing (FDD) provides simultaneous radio transmission channels for the subscriber and the base station, so that they both may constantly transmit while simultaneously receiving signals from one another. At the base station, separate transmit and receive antennas are used to accommodate the two separate channels. At the subscriber unit, however, a single antenna is used for both transmission to and reception from the base station, and a device called a duplexer is used inside the subscriber unit to enable the same antenna to be used for simultaneous transmission and reception. To facilitate FDD, it is necessary to separate the transmit and receive frequencies by about 5% of the nominal RF frequency, so that the duplexer can provide sufficient isolation while being inexpensively manufactured. FDD is always used in analog mobile radio systems.

Time division duplexing (TDD) uses the fact that it is possible to share a single radio channel in time, so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station. If the data transmission rate in the channel is much greater than the end-user's data rate, it becomes possible to store information bursts and provide the appearance of full duplex operation to a user, even though there are not two simultaneous radio transmissions at any instant of time. TDD is only possible with digital transmission formats and digital modulation, and is very sensitive to timing. It is for this reason that TDD has only recently been used, and only for indoor or small area wireless applications, where the physical
coverage distances (and thus the radio propagation time delay) are much smaller than the many kilometers used in conventional cellular telephone systems.

In FDD, a pair of simplex channels with a fixed and known frequency separation are used to define a specific radio channel in the system. The channel used to convey traffic to the mobile user from a base station is called the forward channel, while the channel used to carry traffic from the mobile user to a base station is called the reverse channel. In the AMPS standard, the reverse channel has a frequency which is exactly 45 MHz lower than the forward channel. Full duplex mobile radio systems provide many of the capabilities of standard telephone, with the added convenience of mobility. Full duplex and half-duplex systems use transceivers for radio communication, which is a combination transmitter and receiver in a single piece of equipment.

2.1 Paging Systems

Paging systems are typically communication systems which send brief messages to a subscriber. Depending on the type of service, the message may be either a numeric message, an alphanumeric message, or a voice message. Paging systems are typically used to notify a subscriber of the need to call a particular telephone number or to travel to a known location to receive further instructions. Anyone may send a message to a paging subscriber by dialing the paging system access number (usually a toll-free telephone number) and using a telephone keypad or modem to issue a message, called a page. The paging system then transmits the page throughout the service area using base stations which broadcast the page on a radio carrier.

Paging systems vary widely in their complexity and coverage area. While simple paging systems may cover a limited range of 2-5 km, wide area paging systems may provide worldwide coverage. Though paging receivers are simple and inexpensive, the transmission system required can be quite sophisticated. Wide area paging systems consist of a network of telephone lines, large radio towers, and satellite links that simultaneously dispatch a page to many base station transmitters (this is called simulcasting) that may be located within the same service area or in different cities or countries. Paging systems are designed to provide reliable communication to subscribers wherever they are, whether inside buildings, driving on a highway, or flying in an airplane. This necessitates large transmitter powers (on the order of kilowatts) and low data rates (a couple of thousand bits per second) for maximum coverage from each base station.

2.2 Cordless Telephone Systems

Cordless telephone systems are full duplex communication systems that use radio to connect a portable handset to a dedicated base station, which is then connected to a dedicated telephone line with a specific telephone number on the Public Switched Telephone Network (PSTN). In first generation cordless telephone systems (manufactured in the late 1980's), the portable unit communicates only to the dedicated base unit, and only over distances of a few tens of meters. Early cordless telephones operate solely as extension telephones to a transceiver connected to a subscriber line on the PSTN, and were developed primarily for in-home use. Second generation cordless telephones have recently been introduced which allow subscribers to use their handsets at many outdoor locations within urban centers such as London or Hong Kong. Modern cordless telephones are sometimes combined with paging receivers so that a subscriber may first be paged, and then respond to the page using the cordless telephone. Cordless telephone systems provide the user with limited range and mobility, as it is usually not possible to maintain a call if the user travels outside the range of the base station. Typical second generation base stations provide coverage ranges up to a few hundred meters.

2.3 Cellular Telephone Systems

A cellular telephone system provides wireless access to the PSTN for any user located within the radio range of the system. Cellular systems accommodate a large number of users over a large geographic area, within a limited frequency spectrum. Cellular radio systems provide high quality service, often comparable to that of the land line telephone systems. High capacity is achieved by limiting the coverage of each base station transmitter to a small geographic area called a cell so that the same
radio channels may be reused by another transmitter located a small distance away. A sophisticated switching technique called a hand-off enables a call to proceed uninterrupted when the user moves from one cell to another.

Figure 2 shows a basic cellular system which consists of mobile stations, base stations and a Mobile Switching Center (MSC). The Mobile Switching Center is sometimes called the Mobile Telephone Switching Office (MTSO), since it is responsible for connecting all mobiles to the PSTN in a cellular system. Each mobile user communicates via radio with one of the base stations, and may be handed-off to any number of base-stations throughout the duration of a call. The mobile station contains a transceiver, an antenna, and control circuitry, and may be mounted in a vehicle or used as a portable hand held. The base stations consist of several transmitters and receivers which simultaneously handle full duplex communications, and generally have towers which support several transmitting and receiving antennas. The base station serves as a bridge between all mobile users in a geographic area and connects the simultaneous mobile calls via telephone lines or microwave links to the MSC. The MSC coordinates the activities of all the base stations and connects the entire cellular system to the PSTN. A typical MSC can handle 5,000 simultaneous cellular conversations and 100,000 possible subscribers at a time, and handles all billing and system maintenance functions, as well.

Communication between the base station and the mobile takes places over four different channels. The channels used for voice transmission from base station to mobile are called the Forward Voice Channels (FVC) and the channels used for voice transmission from mobile to base station are called the Reverse Voice Channels (RVC). The two channels responsible for initiating each call are the Forward Control Channels (FCC) and Reverse Control Channels (RCC). Control channels are often referred to as setup channels because they are only involved in setting up a call and moving it to an unused voice channel. Control channels transmit and receive data messages that carry call initiation and service requests, and are always monitored by mobiles that do not have an active call in progress. Forward control channels, in fact, serve as beacons which continually broadcast all of the traffic requests for all mobiles in the system. Supervisory and data messages are sent in a number of ways to facilitate automatic changes in mobile transmitter power and hand-off of the mobiles between neighboring base stations while a call is in progress.
3. Mobile Radio Telephone Throughout the World

The first generation U.S. cellular standard is called AMPS, which stands for Advanced Mobile Phone Service. AMPS was developed in 1983 and uses 30 kHz FM channels for each subscriber (see Figure 3 for AMPS channel allocation scheme).

In the late 1980's, the European technical community, under the auspices of Confe'rence of Europe'ene Postes des et Te'le'communication (CEPT), developed the world's first digital cellular radio standard known as Groupe Speciale Mobile (GSM). In 1993, GSM was renamed Global System for Mobile communications, reflecting its growing worldwide popularity. Today, GSM is deployed in every continent which has cellular radio service.

In late 1991, the first U.S. Digital Cellular (USDC) system hardware was installed in major U.S. cities. The USDC standard (Electronic Industry Association Interim Standard IS-54) allows cellular operators to gracefully replace some single-user analog channels with digital channels which support three users in the same 30 kHz bandwidth [6]. In this way, U.S. carriers can gradually phase out AMPS as more users accept digital phones. The capacity improvement offered by USDC is three times that of AMPS, simply because digital modulation (π/4 Differential Quadrature Phase Shift Keying), speech coding, and time division multiple access (TDMA) are used in place of analog FM. Given the rate of digital signal processing advancements, speech coding technology will increase the capacity to 6-users-per-channel in the same 30 kHz bandwidth within a few years.

A cellular system based on code division multiple access (CDMA) has been developed by Qualcomm, Inc. and standardized by the Telecommunications Industry Association (TIA) as an Interim Standard (IS-95). This system supports a variable number of users in 1.25 MHz wide channels using direct sequence spread spectrum. While the analog AMPS system requires that the signal be at least 18 dB above the co-channel interference to provide acceptable call quality, CDMA systems can operate in much larger interference levels because of their inherent interference resistance properties. The ability of CDMA to operate with a much smaller signal to noise ratio than conventional narrow band FM techniques allows CDMA systems to use the same set of frequencies in every cell, which provides a large improvement in capacity [7]. Unlike other digital cellular systems, the Qualcomm system uses a variable rate vocoder with voice activity detection which considerably reduces the effective data rate and also the battery drain.

In 1992, Motorola developed narrowband AMPS (NAMPS) which has been used in the U.S. and South America to provide additional capacity using standard analog AMPS techniques. NAMPS provides three users on a single 30 kHz AMPS channel by using 10 kHz FM channels per user.

In the early 1990's, a new specialized mobile radio service (SMR) has been developed to compete with U.S. cellular radio carriers. By buying small groups of radio system licenses from a large number of independent private radio service providers throughout the country, Nextel and Motorola have formed an extended SMR (E-SMR) network in the 800 MHz band that could provide capacity and services similar to cellular. New Personal Communication Service (PCS) licenses in the 1800/1900 MHz band were auctioned to wireless providers in early 1995, and promise to spawn new wireless service providers that will complement, as well as compete with, cellular. SMR is also being deployed in Mexico and South America.

From the above discussion, it should be clear that there are a repertoire of mobile radio standards which have been developed for wireless systems throughout the world, and many more standards are likely to emerge. Table 1 through Table 3 provide a listing of the most common paging, cordless, cellular, and personal communications standards in North and South America, Europe, and Japan.

The world’s most common paging standard is the Post Office Code Standard Advisory Group (POCSAG) [8],[9]. POCSAG was developed by British Post Office in the late 1970’s and supports binary frequency shift keying (FSK) signaling at 512 bps, 1200 bps, and 2400 bps. New paging systems, such as FLEX and ERMES, provide up to 6400 bps transmissions by using 4-level modulation, and are currently being deployed throughout the world.
The CT-2 and DECT standards developed in Europe are the two most popular cordless telephone standards throughout Europe and Asia. The CT-2 system makes use of microcells which cover small distances, usually less than 100 m, using base stations with antennas mounted on street lights or on sides of buildings. The CT-2 system uses battery efficient frequency shift keying along with a 32 kbps Adaptive Differential Pulse Code Modulation (ADPCM) speech coder for high quality voice transmission. Hand-offs are not supported in CT-2, as it is intended to provide short range access to the PSTN. The DECT system accommodates data and voice transmissions for office and business users. In the U.S. the PACS standard, developed by Bellcore and Motorola, is likely to be used inside office buildings as a wireless voice and data telephone system or radio local loop. The PHP standard supports indoor and local loop applications in Japan.

The world's first cellular system was implemented by the Nippon Telephone and Telegraph company (NTT) in Japan. The system was deployed in 1979 and used 600 FM duplex channels (25 kHz for each one-way link) in the 800 MHz band. In Europe, the Nordic Mobile Telephone system (NMT 450) was developed in 1981 for the 450 MHz band, and uses 25 kHz channels. The Extended European Total Access Cellular System (ETACS) was deployed in 1985 and is virtually identical to the U.S. AMPS system, except that the smaller bandwidth channels result in a slight degradation of signal-to-noise ratio (SNR) and coverage range. In Germany, a cellular standard called C-450 was introduced in 1985. The first generation European cellular systems are generally incompatible with one another because of the different frequencies and communication protocols used. These systems are now being replaced by the Pan European digital cellular standard GSM (Global System Mobile) which was first deployed in 1991 in a new 900 MHz band which all of Europe dedicated for cellular telephone service [10]. The GSM standard is gaining worldwide acceptance as the first universal digital cellular system with modern network features extended to each mobile user, and is a strong contender for PCS services above 1800 MHz throughout the world. In Japan, the PDC standard provides digital cellular coverage using a system similar to America's USDC.
### Table 1: Major Mobile Radio Standards in The Americas

<table>
<thead>
<tr>
<th>Standard</th>
<th>Type</th>
<th>Year of Introduction</th>
<th>Multiple Access</th>
<th>Frequency Band</th>
<th>Modulation</th>
<th>Channel Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMPS</td>
<td>Cellular</td>
<td>1983</td>
<td>FDMA</td>
<td>824-894 MHz</td>
<td>FM</td>
<td>30 kHz</td>
</tr>
<tr>
<td>NAMPS</td>
<td>Cellular</td>
<td>1992</td>
<td>FDMA</td>
<td>824-894 MHz</td>
<td>FM</td>
<td>10 kHz</td>
</tr>
<tr>
<td>USDC</td>
<td>Cellular</td>
<td>1991</td>
<td>TDMA</td>
<td>824-894 MHz</td>
<td>π/4-DQPSK</td>
<td>30 kHz</td>
</tr>
<tr>
<td>CDPD</td>
<td>Cellular</td>
<td>1993</td>
<td>FH/Packet</td>
<td>824-894 MHz</td>
<td>GMSK</td>
<td>30 kHz</td>
</tr>
<tr>
<td>IS-95</td>
<td>Cellular/PCS</td>
<td>1993</td>
<td>CDMA</td>
<td>824-894 MHz</td>
<td>QPSK/BPSK</td>
<td>1.25 MHz</td>
</tr>
<tr>
<td>GSC</td>
<td>Paging</td>
<td>1970's</td>
<td>Simplex</td>
<td>Several</td>
<td>FSK</td>
<td>12.5 kHz</td>
</tr>
<tr>
<td>POCSAG</td>
<td>Paging</td>
<td>1970's</td>
<td>Simplex</td>
<td>Several</td>
<td>FSK</td>
<td>12.5 kHz</td>
</tr>
<tr>
<td>FLEX</td>
<td>Paging</td>
<td>1993</td>
<td>Simplex</td>
<td>Several</td>
<td>4-FSK</td>
<td>15 kHz</td>
</tr>
<tr>
<td>DCS (GSM)</td>
<td>PCS</td>
<td>1993</td>
<td>TDMA</td>
<td>1.85-1.99 GHz</td>
<td>GMSK</td>
<td>200 kHz</td>
</tr>
<tr>
<td>PACS</td>
<td>Cordless/PCS</td>
<td>1994</td>
<td>TDMA/FDMA</td>
<td>1.85-1.99 GHz</td>
<td>π/4-DQPSK</td>
<td>300 kHz</td>
</tr>
<tr>
<td>MIRS</td>
<td>SMR/PCS</td>
<td>1994</td>
<td>TDMA</td>
<td>Several</td>
<td>16-QAM</td>
<td>25 kHz</td>
</tr>
</tbody>
</table>

### Table 2: Major Mobile Radio Standards in Europe

<table>
<thead>
<tr>
<th>Standard</th>
<th>Type</th>
<th>Year of Introduction</th>
<th>Multiple Access</th>
<th>Frequency Band</th>
<th>Modulation</th>
<th>Channel Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-TACS</td>
<td>Cellular</td>
<td>1985</td>
<td>FDMA</td>
<td>900 MHz</td>
<td>FM</td>
<td>25 kHz</td>
</tr>
<tr>
<td>NMT-450</td>
<td>Cellular</td>
<td>1981</td>
<td>FDMA</td>
<td>450-470 MHz</td>
<td>FM</td>
<td>25 kHz</td>
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<tr>
<td>NMT-900</td>
<td>Cellular</td>
<td>1986</td>
<td>FDMA</td>
<td>890-960 MHz</td>
<td>FM</td>
<td>12.5 kHz</td>
</tr>
<tr>
<td>GSM</td>
<td>Cellular/PCS</td>
<td>1991</td>
<td>TDMA</td>
<td>890-960 MHz</td>
<td>GMSK</td>
<td>200 kHz</td>
</tr>
<tr>
<td>C-450</td>
<td>Cellular</td>
<td>1985</td>
<td>FDMA</td>
<td>450-465 MHz</td>
<td>FM</td>
<td>20 kHz/10kHz</td>
</tr>
<tr>
<td>ERMES</td>
<td>Paging</td>
<td>1993</td>
<td>FDMA</td>
<td>Several</td>
<td>4-FSK</td>
<td>25 kHz</td>
</tr>
<tr>
<td>CT-2</td>
<td>Cordless</td>
<td>1989</td>
<td>FDMA</td>
<td>864-868 MHz</td>
<td>GFSK</td>
<td>100 kHz</td>
</tr>
<tr>
<td>DECT</td>
<td>Cordless</td>
<td>1993</td>
<td>TDMA</td>
<td>1880-1900 MHz</td>
<td>GFSK</td>
<td>1.728 MHz</td>
</tr>
<tr>
<td>DCS-1800</td>
<td>Cordless/PCS</td>
<td>1993</td>
<td>TDMA</td>
<td>1710-1880 MHz</td>
<td>GMSK</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Standard</td>
<td>Type</td>
<td>Year of Introduction</td>
<td>Multiple Access</td>
<td>Frequency Band</td>
<td>Modulation</td>
<td>Channel Bandwidth</td>
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</tr>
<tr>
<td>JTACS</td>
<td>Cellular</td>
<td>1988</td>
<td>FDMA</td>
<td>860-925 MHz</td>
<td>FM</td>
<td>25 kHz</td>
</tr>
<tr>
<td>PDC</td>
<td>Cellular</td>
<td>1993</td>
<td>TDMA</td>
<td>810-1507 MHz</td>
<td>π/4-DQPSK</td>
<td>25 kHz</td>
</tr>
<tr>
<td>NTT</td>
<td>Cellular</td>
<td>1979</td>
<td>FDMA</td>
<td>400/800 MHz</td>
<td>FM</td>
<td>25 kHz</td>
</tr>
<tr>
<td>NTACS</td>
<td>Cellular</td>
<td>1993</td>
<td>FDMA</td>
<td>843-925 MHz</td>
<td>FM</td>
<td>12.5 kHz</td>
</tr>
<tr>
<td>NTT</td>
<td>Paging</td>
<td>1979</td>
<td>FDMA</td>
<td>280 MHz</td>
<td>FSK</td>
<td>12.5 kHz</td>
</tr>
<tr>
<td>NEC</td>
<td>Paging</td>
<td>1979</td>
<td>FDMA</td>
<td>Several</td>
<td>FSK</td>
<td>10 kHz</td>
</tr>
<tr>
<td>PHP</td>
<td>Cordless</td>
<td>1993</td>
<td>TDMA</td>
<td>1895-1907 MHz</td>
<td>π/4-DQPSK</td>
<td>300 kHz</td>
</tr>
</tbody>
</table>

4. Trends in Cellular Radio and Personal Communications

Since 1989, there has been enormous activity throughout the world to develop personal wireless systems that combine the network intelligence of today's PSTN with modern digital signal processing and RF technology. The concept, called Personal Communication Services (PCS), originated in the U.K. when three companies were given spectrum in the 1800 MHz to develop Personal Communication Networks (PCN) throughout Great Britain [11]. PCN was seen by the U.K. as a means of improving its international competitiveness in the wireless field while developing new wireless systems and services for citizens. Presently, field trials are being conducted throughout the world to determine the suitability of various modulation, multiple-access, and networking techniques for future PCN and PCS systems. (The terms PCN and PCS are often used interchangeably. PCN refers to a wireless networking concept where any user can make or receive calls, no matter where they are, using a lightweight, personalized communicator. PCS refers to new wireless systems that incorporate more network features and are more personalized than existing cellular radio systems, but which do not embody all of the concepts of an ideal PCN).

Indoor wireless networking products are steadily emerging and promise to become a major part of the telecommunications infrastructure within the next decade. An international standards body, IEEE 802.11, is working on standards for wireless access between computers inside buildings. The European Telecommunications Standard Institute (ETSI) is also developing the 20 Mbps HIPERLAN standard for indoor wireless networks. Recent products such as Motorola's 18 GHz WIN (wireless information network) modem and AT&T's (formerly NCR) waveLAN computer modem have been available as wireless ethernet connections since 1990, and are beginning to penetrate the business world [12]. Before the end of the 20th century, products will allow a user to link their phone with their computer within an office environment, as well as in a public setting, such as an airport or train station.

A world-wide standard, the Future Public Land Mobile Telephone System (FPLMTS), is being formulated by the International Telecommunications Union (ITU), the standards body for the United Nations, with headquarters in Geneva, Switzerland. The technical group TG 8/1 standards task group is within the ITU's Radiocommunications Sector (ITU-R), formerly known as the Consultative Committee for International Radiocommunications (CCIR). TG 8/1 is considering how future PCNs should evolve, and how worldwide frequency coordination might be implemented to allow subscriber units to work anywhere in the world. FPLMTS is a third generation universal, multi-function, globally compatible digital mobile radio system that would integrate paging, cordless and cellular systems, as well as low earth orbit (LEO) satellites, into one universal mobile system. A total of 230 MHz in frequency bands 1885-2025 MHz and 2110-2200 MHz has been targeted by the ITU's 1992 World Administrative Radio Conference (WARC) for FPLMTS. The type of modulation, speech coding and multiple access schemes to be used in FPLMTS are yet to be decided.

World-wide standards are now required for emerging LEO satellite communication systems that are in the design and prototyping stage. Due to the very large areas on earth which are illuminated by satellite transmitters, satellite-based cellular systems will never approach the capacities provided by

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Table 3 Major Mobile Radio Standards in Japan

<table>
<thead>
<tr>
<th>Standard</th>
<th>Type</th>
<th>Year of Introduction</th>
<th>Multiple Access</th>
<th>Frequency Band</th>
<th>Modulation</th>
<th>Channel Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTACS</td>
<td>Cellular</td>
<td>1988</td>
<td>FDMA</td>
<td>860-925 MHz</td>
<td>FM</td>
<td>25 kHz</td>
</tr>
<tr>
<td>PDC</td>
<td>Cellular</td>
<td>1993</td>
<td>TDMA</td>
<td>810-1507 MHz</td>
<td>π/4-DQPSK</td>
<td>25 kHz</td>
</tr>
<tr>
<td>NTT</td>
<td>Cellular</td>
<td>1979</td>
<td>FDMA</td>
<td>400/800 MHz</td>
<td>FM</td>
<td>25 kHz</td>
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<tr>
<td>NTACS</td>
<td>Cellular</td>
<td>1993</td>
<td>FDMA</td>
<td>843-925 MHz</td>
<td>FM</td>
<td>12.5 kHz</td>
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<tr>
<td>NTT</td>
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<td>1979</td>
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<td>1993</td>
<td>TDMA</td>
<td>1895-1907 MHz</td>
<td>π/4-DQPSK</td>
<td>300 kHz</td>
</tr>
</tbody>
</table>
land-based microcellular systems. However, satellite mobile systems offer tremendous promise for paging, data collection, and emergency communications, as well as for global roaming before FPLMTS is deployed. In early 1990, the aerospace industry demonstrated the first successful launch of a small satellite on a rocket from a jet aircraft. This launch technique is more than an order of magnitude less expensive than conventional ground-based launches, and can be deployed quickly, suggesting that a network of LEO's could be rapidly deployed for wireless communications around the globe. Already, several companies have proposed systems and service concepts for world-wide paging, cellular telephone, and emergency navigation and notification [13].

In emerging nations, where existing telephone service is almost non-existent, fixed cellular telephone systems are being installed at a rapid rate. This is due to the fact that developing nations are finding that it is much quicker and more affordable to install cellular telephone systems for fixed home use, rather than install wires to neighborhoods which have not yet received telephone connections to the PSTN.

The world is now in the early stages of a major telecommunications revolution that will provide ubiquitous communication access to citizens, wherever they are [14], [15], [16]. This new field requires engineers who can design and develop new wireless systems, make meaningful comparisons of competing systems, and understand the engineering trade-offs that must be made in any system. Such understanding can only be achieved by mastering the fundamental technical concepts of wireless personal communications [17].

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AUTHOR(S): T S Rappaport

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