FOCUSED ISSUE FEATURE

Wireless Communications: Present and Future

Edward C. Niehenke

This special issue "Wireless Communications: Present and Future" has been prepared by members of the IEEE Microwave Theory and Techniques (MTT)-20 Technical Committee, "Wireless Communications." This area of technology has experienced an explosion of growth. This introduction traces the technology developments to the present. Future wireless communication developments are presented in four articles in this special issue.

Transoceanic Communication

In 1896, Guglielmo Marconi (Figure 1) developed the first wireless telegraph system. In December 1901, he used his system for transmitting the first wireless signals across the Atlantic between Poldhu, Cornwall, and St. John's, Newfoundland, a distance of 2,100 miles [1].

Radio Development

Amplitude modulated (AM) radio began with the first experimental broadcast in 1906 by Reginald Fessenden (Figure 2) and was used for small-scale voice and music broadcasts up until World War I. On the evening of 24 December 1906, Fessenden used the alternator-transmitter to send out a short program from Brant Rock, which included his playing the song "O Holy Night" on the violin and reading a passage from the Bible [2], [3]. The great increase in the use of AM radio came the following decade. The first licensed commercial radio services began on AM in the 1920s.

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Edward C. Niehenke (e.niehenke@ieee.org) is with Niehenke Consulting, 5829 Bellanca Drive, Elkridge, Maryland 21075 United States.

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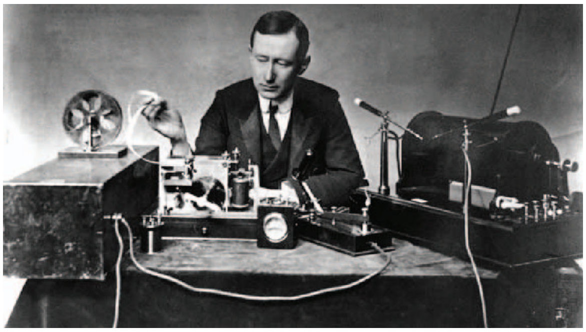

Figure 1. *Marconi operating an apparatus similar to that used by him to transmit the first wireless signal across the Atlantic in 1901. (Source: Wikimedia Commons.)*

Edwin Armstrong (Figure 3) was one of the most prolific inventors of the radio era, with a vision that was ahead of his time [4]–[8]. He invented the regenerative circuit (invented while he was a junior in college at Columbia University, New York City, and patented 1914), the superregenerative circuit (patented 1922), and the superheterodyne receiver (patented 1918). Armstrong had realized that higher-frequency equipment would allow detection of enemy shipping much more effectively, but at the time, no practical short-wave amplifier existed. In those days "short wave" meant anything above 500 KHz. Armstrong mixed the high-frequency signal down to a lower frequency, which was far more amenable to high-gain amplification using triodes.

While working in the basement lab of Columbia's Philosophy Hall, Armstrong created frequency modulation (FM) radio [56]. Rather than varying the amplitude of a radio wave to create sound, Armstrong's method varied the frequency of the wave instead. FM radio receivers proved to generate a much clearer sound, free of static, than the AM radio dominant at the time.

In 1947, the transistor was invented by scientists John Bardeen, Walter Brattain, and William Shockley.

Radar Development

Radar can be traced back to the work of Heinrich Hertz in the late 19th century that showed that radio waves were reflected by metallic objects. This possibility was suggested in James Clerk Maxwell's seminal work on electromagnetism [9]. Christian Hülsmeyer, the German inventor, built and demonstrated on 9 June 1904 a simple ship detection device intended to help avoid collisions in fog [10].

In the 1934–1939 period, eight nations developed, independently and in great secrecy, radar systems: the United States, Great Britain, Germany, the USSR, Japan, The Netherlands, France, and Italy. In addition, Great Britain had shared their basic information with four Commonwealth countries: Australia, Canada, New Zealand, and South Africa, and these countries had also developed indigenous radar systems. During the war, Hungary was added to this list [11].

The term "RADAR" was coined in 1940 by the United States Signal Corps as an acronym for radio detection

Figure 2. *Reginald Fessenden, the father of radio broadcasting. (Source: Wikimedia Commons.)*

Figure 3. *Edwin Armstrong, the creator of FM radio. (Source: Wikimedia Commons.)*

The GPS project was developed in 1973 [45] to overcome the limitations of previous navigation systems.

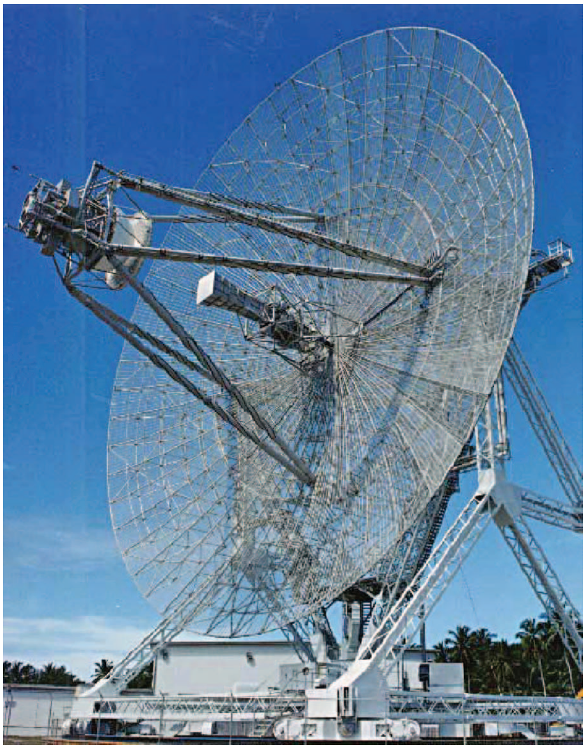

Figure 4. *A long-range radar antenna, used to track space objects and ballistic missiles. (Source: Wikimedia Commons.)*

and ranging. The range of the object is obtained by measuring the time difference between the return signal and transmitted signal, while the velocity of the object is determined by the difference between the received frequency

Figure 6. *A LORAN-C receiver for use on merchant ships. (Source: Wikimedia Commons: Morn the Gorn.)*

and the transmitted frequency of the signal (Doppler frequency shift) [12]. Figure 4 shows a large radar antenna used to track space objects as well as ballistic missiles.

Radar, in addition to its military applications, has found use in civilian applications such as airport air traffic control, weather mapping, automobile collision avoidance, speed guns, police detectors, Doppler sensors for occupancy monitoring [13], experimental demonstration of noncontact pulse-wave velocity monitoring using multiple Doppler sensors [14], as well as numerous other applications.

Transistor Invention

In 1947, the transistor was invented by scientists John Bardeen, Walter Brattain, and William Shockley (Figure 5) who later shared the Nobel Prize [15]. The transistor replaced vacuum tubes, serving as the foundation for the development of modern electronics and making possible the marriage of computers and communications.

Figure 5. *Photo of (from left) John Bardeen, William Shockley, and Walter Brattain, the inventors of the transistor. (Source: Wikimedia Commons.)*

LORAN Navigation System

Long-range navigation (LORAN) [16], [17] is a terrestrial radio navigation system that enables ships and aircraft to determine their position and speed from low-frequency (LF) radio signals transmitted by fixed land-based radio beacons using a receiver unit. LORAN was an American development, advancing the technology of the British Generalized Estimating Equation (GEE) radio navigation system that was used early in World War II. It originally was known as Loomis radio navigation (LRN) after Alfred Lee Loomis, who invented the longer-range system and played a crucial role in military research and development during World War II. Later, GEE was adopted instead of the more descriptive term. LORAN systems were built during World War II after development at the Massachusetts Institute of Technology (MIT) Radiation Laboratory and were used extensively by the U.S. Navy and the Royal Navy. The British Royal Air Force also used LORAN on raids beyond the range of GEE.

The most recent version of LORAN is LORAN-C [18], which operates in the LF portion of the radio spectrum from 90 to 110 kHz (Figure 6). Many nations have used the system, including the United States, Japan, and several European countries. Russia uses a nearly identical system in the same frequency range, called "chayka" (Russian for "seagull"). In recent decades, LORAN use has been in steep decline, with the satellite-based global positioning system (GPS) being the primary replacement.

Automobile Mobile Telephone Service

In the United States, engineers from Bell Labs began work on a system to allow mobile users to place and receive telephone calls from automobiles, leading to the inauguration of mobile service on 17 June 1946, in St. Louis, Missouri [19]. Shortly after, AT&T offered mobile telephone service. The introduction of cellular technology, which allowed reuse of frequencies many times in small adjacent areas covered by relatively low-powered transmitters, made widespread adoption of mobile telephones economically feasible.

Information Theory

Claude Elwood Shannon (1916–2001) (Figure 7) was an American mathematician, electronic engineer, and cryptographer known as "the father of information theory" [20], [21]. Shannon is famous for having founded information theory with a landmark paper that he published in 1948 [22]. This paper contains the basis for data compression (source encoding) and error detection and correction (channel encoding). However, he is also credited with founding both digital computer and digital circuit design theory in 1937, when, as a 21-year-old master's degree student at MIT, he wrote his thesis demonstrating that electrical applications of boolean algebra could construct and resolve any logical, numerical relationship. A version of the paper was published in the 1938 issue of *Transactions of the American Institute of Electrical Engineers* [23] and in 1940, it earned Shannon the Alfred Noble American Institute of American Engineers Award. It has been claimed that this was the most important master's thesis of all time [24]. Shannon contributed to the field of cryptanalysis for national defense during World War II, including his basic work on code breaking and secure telecommunications.

Shannon provided major contributions to modern communication theory. Shannon showed [22] that the system capacity, C, of a channel perturbed by additive white Gaussian noise (AWGN) is a function of the average received signal, S, the average noise power, N, and the bandwidth, W. This Shannon–Hartley theory is stated as

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$$C = W\log_2\left(1 + \frac{S}{N}\right),$$

where W is in hertz, and the capacity is in bits/s. It is theoretically possible to transmit information over such a channel at any rate, R, where $R \geq C$, with any arbitrary small error probability by using a sufficiently complicated coding scheme. For $R < C$, it is not possible. This important relationship provided a limit to the maximum capacity of a channel in terms of the signal to noise.

Other communication contributions of Shannon's [20] include:

- Shannon–Fano coding
- Nyquist–Shannon sampling theorem
- noisy channel coding theorem
- rate distortion theory
- information theory
- channel capacity

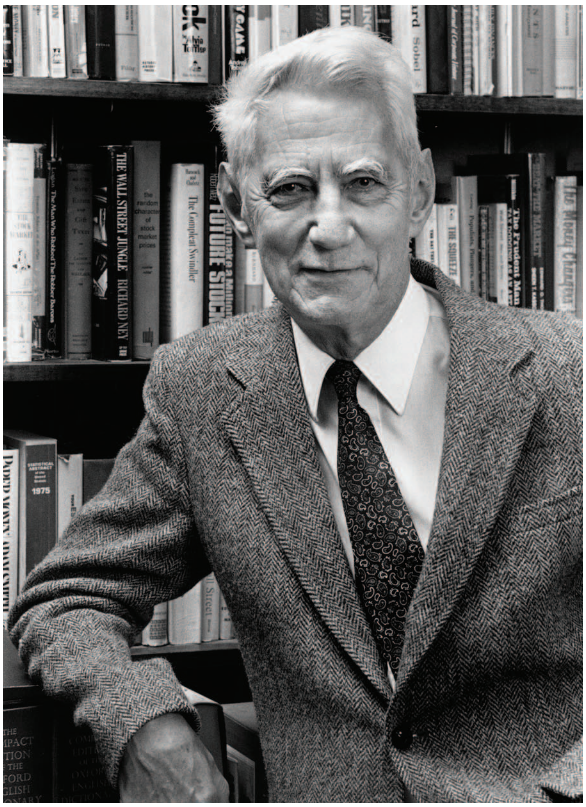

Figure 7. *Claude Elwood Shannon,"the father of information theory." (Photo Reprinted with permission of Alcatel-Lucent USA Inc.)*

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- confusion and diffusion
- Shannon number
- Shannon index
- Shannon's source coding theorem
- information entropy
- Shannon's expansion.

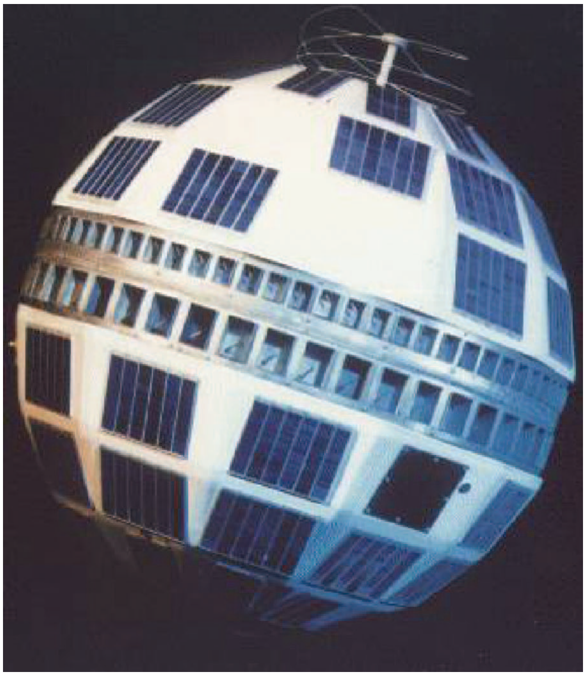

Figure 8. *The original Telstar had a roughly spherical shape. (Source: Wikimedia Commons.)*

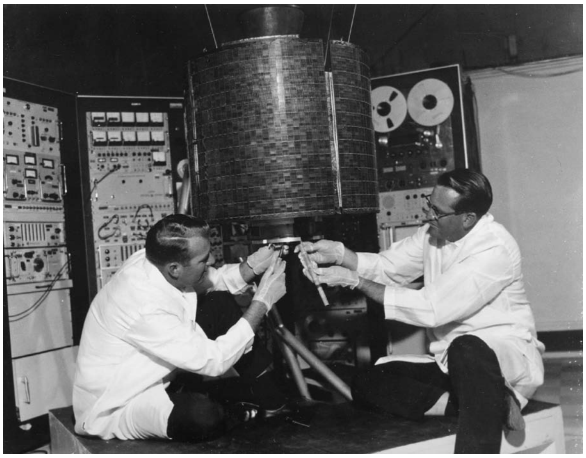

Figure 9. *Engineers (from left) Stanley R. Peterson and Ray Bowerman check out the Early Bird—the world's first communication satellite. (Source: Wikimedia Commons.)*

Television Development

In the 1930s, analog television (TV) broadcasting began [25]. In 1953, the National Television System Committee (NTSC) color TV system was introduced in the United States [26]. In 1960, color broadcasting was standardized on the phase alternating line (PAL) format in Europe [27], with broadcasts starting in 1967. By this point, many of the technical problems in the early sets had been worked out, and the spread of color sets in Europe was fairly rapid.

High-definition TV (HDTV) technology was introduced in the United States in the 1990s by the Digital HDTV Grand Alliance, a group of television, electronic equipment, communications companies consisting of AT&T Bell Labs, General Instrument, Philips, Sarnoff, Thomson, Zenith, and MIT. The first public HDTV broadcast in the United States occurred on 23 July 1996 [28].

The first regular HDTV broadcasts in Europe started on 1 January 2004, when the Belgian company Euro1080 launched the HD1 channel with the traditional Vienna New Year's concert. Test transmissions had been active since the International Broadcasting Convention (IBC) exhibition in September 2003, but the New Year's Day broadcast marked the official launch of the HD1 channel and the official start of direct-to-home HDTV in Europe [29].

Radio Development

In 1954, Regency introduced a pocket transistor radio, the TR-1 [30], powered by a standard 22.5-V battery. In 1960, Sony introduced their first transistorized radio [31], small enough to fit in a vest pocket and able to be powered by a small battery. It was durable because there were no tubes to burn out. Over the next 20 years, transistors displaced tubes almost completely, except for very high-power or very high frequency uses.

Satellite radio is a radio service broadcast from satellites primarily to cars, with the signal broadcast nationwide, across a much wider geographical area than terrestrial radio stations, while transmitting higher-quality sound [32], [33]. It is available by subscription, mostly commercial free, and offers subscribers more stations and a wider variety of programming options than terrestrial radio [34].

In 1994, the U.S. Army and Defense Advanced Research Projects Agency (DARPA) launched an aggressive successful project to construct a software radio that could become a different radio on the fly by changing software [35].

Radio Communication Satellite Systems

In 1963, the first (radio) communication satellite, Telstar, was launched. The first two Telstar satellites were experimental and nearly identical. Telstar 1 (Figure 8) was launched on top of a Thor-Delta rocket on 10 July 1962. It successfully relayed through space

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the first television pictures, telephone calls, and fax images and provided the first live transatlantic television feed. Telstar 2 was launched 7 May 1963 [36], [37]. Telstar 1 and 2, though no longer functional, are still in orbit.

On 20 August 1964 the International Telecommunications Satellite Consortium (INTELSAT) was established as a public-private consortium by the telecommunication agencies of 18 nations, including the United States, which proposed the organization. The consortium contracted with the U.S. National Aeronautics and Space Administration (NASA) to launch its satellites.

In April 1965, the Communications Satellite Corporation (COMSAT) was responsible for the launching of the Intelsat I communications satellite [38], [39], which was nicknamed "Early Bird" for the proverb "the early bird catches the worm," and was placed into geosynchronous orbit. Modern communications satellites use geosynchronous orbits, Molniya (highly elliptical) orbits, or low-polar Earth orbits. The Early Bird satellite was the first to provide direct and nearly instantaneous contact between Europe and North America, handling television, telephone, and telefacsimile transmissions. It was fairly small, measuring nearly 76 × 61 cm (2.5 × 2.0 ft) and weighing 76 lb (Figure 9).

It helped provide the first live TV coverage of a spacecraft splashdown, that of Gemini 6 in December 1965. Originally slated to operate for 18 months, Early Bird was in active service for four years, being deactivated in January 1969, although it was briefly activated in June of that year to serve the Apollo 11 flight when the Atlantic Intelsat satellite failed. It was deactivated again in August 1969, and has been inactive since that time (except for a brief reactivation in 1990 to commemorate its 25th launch anniversary), although it remains in orbit.

Internet Development

In 1968, DARPA selected Bolt, Beranek, and Newman (BBN) Technologies to develop the Advanced Research Projects Agency Network (ARPANET), the precursor of the modern Internet [40]. In 1982, the Internet protocol suite (TCP/IP) connection was introduced and the worldwide network of interconnected TCP/IP networks, called the Internet, was introduced [41].

Since the mid-1990s [42], the Internet has had a revolutionary impact on culture and commerce, including the rise of near-instant communication by electronic mail, instant messaging, Voice over Internet Protocol (VoIP) "phone calls," two-way interactive video calls, and the World Wide Web with its discussion forums, blogs, social networking, and online shopping sites. Increasing amounts of data are transmitted at higher speeds over fiber optic networks operating at 1-Gb/s, 10-Gb/s, or more. The Internet's takeover of the global communication landscape was almost instant in historical time scales. Today, the Internet continues to grow, driven by ever greater amounts of online information, commerce, entertainment, and social networking.

Personal Computers

During the 1970s and early 1980s, major developments were made with the personal computer (PC), and, in 1982, the computer was named "Machine of the Year" by *Time Magazine*. Notebook (laptop) transportable computers are very popular today and, in many cases, are replacing the PC due to their portability. Netbooks (also called mini notebooks or subnotebooks) are a rapidly evolving category of small, light, and inexpensive laptop computers suited for general computing and accessing Web-based applications. A tablet computer, or simply tablet, which is a mobile computer with display, circuitry, and battery in a single unit, is the most

Figure 10. *An Apple iPad tablet. (Photo courtesy of Ed Niehenke.)*

Figure 11. *Martin Cooper holding his DynaTAC cell phone in 2007. (Source: Wikimedia Commons.)*

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recently introduced category. Figure 10 illustrates the Apple iPad. Tablets are often equipped with sensors, including cameras, microphone, accelerometer, and touch screen, with finger or stylus gestures replacing the computer mouse and keyboard.

Initial Mobile Phone Development

Motorola was the first company to produce a handheld mobile phone. On 3 April 1973, Dr. Martin Cooper, a Motorola engineer and executive, made the first mobile telephone call (Figure 11) from handheld subscriber equipment in front of reporters, placing a call to Dr. Joel S. Engel of Bell Labs [43], [44]. The prototype handheld phone used by Cooper weighed 1.1 kg and measured 23-cm long, 13-cm deep, and 4.45-cm wide. The prototype offered a talk time of just 30 min and took ten hours to recharge. Cooper has stated his vision for the handheld device was inspired by Captain James T. Kirk using his communicator on the television show *Star Trek*.

The Global Positioning System

The GPS is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil, and commercial users around the world. It is maintained by the U.S. government and is freely accessible to anyone with a GPS receiver.

The GPS project was developed in 1973 [45] to overcome the limitations of previous navigation systems, integrating ideas from several predecessors, including a number of classified engineering design studies from the 1960s. The GPS was created and realized by the U.S. Department of Defense (DoD) and was originally run with 24 satellites (Figure 12). It became fully operational in 1994. Bradford Parkinson, Roger L. Easton, and Ivan A. Getting are credited with inventing it. Improvements are being made to improve accuracy with the GPS III.

Figure 12. *The GPS uses numerous satellites to determine location. (Photo courtesy of Garmin.)*

Cellular Phone Systems

The cellular phone has progressed over the years with many transformations from analog to digital and associated standards from first generation (1G) to fourth generation (4G) [46]. In 1977, the U.S. Federal Communications Commission (FCC) authorized a developmental cellular systems launch in Chicago and the Washington, D.C./Baltimore region. The first analog cellular system widely deployed in North America was the Advanced Mobile Phone System (AMPS) [47]. It was commercially introduced in the Americas in 1978, Israel in 1986, and Australia in 1987. This system used a frequency-division multiple access (FDMA) scheme and required significant amounts of wireless spectrum.

The first commercially automated cellular network (1G [48]) was launched in Japan by Nippon Telegraph and Telephone (NTT) in 1979, initially in the metropolitan area of Tokyo. Within five years, the NTT network had been expanded to cover the whole population of Japan and became the first nationwide 1G network. In 1981, this was followed by the simultaneous launch of the Nordic Mobile Telephony (NMT) system in Denmark, Finland, Norway, and Sweden. NMT was the first mobile phone network featuring international roaming. The first 1G network launched in the United States was Chicago-based Ameritech in 1983, using the Motorola DynaTAC mobile phone. Several countries then followed in the early to mid-1980s, including the United Kingdom, Mexico, and Canada.

In the 1990s, the second-generation (2G) mobile phone systems emerged [49]. Two systems competed for supremacy in the global market: the European-developed global system for mobile communications (GSM) standard and the U.S.-developed code division multiple access (CDMA) standard. These differed from the previous generation by using digital instead of analog transmission. Nokia was one of the key developers of GSM [50], the 2G mobile technology that could carry data as well as voice traffic. NMT provided valuable experience for Nokia for its close participation in developing GSM, which was adopted in 1987 as the new European standard for digital mobile technology. In 1992, Nokia launched the first GSM phone, the Nokia 1011.

The rise in mobile phone use as a result of 2G was explosive, and this era also saw the advent of prepaid mobile phones. In the United States, digital phones based on the IS54 standard also was deployed in the same band as AMPS and displaced some of the existing analog channels. This system is referred to as digital AMPS and uses time-division multiple access (TDMA) [51]. The digital modulation was $\pi/4$ differential quadrature phase-shift keying (DQPSK) [57]. The digital phones provided three times the number of voice channels compared to the analog phones using the same radio-frequency (RF) bandwidth.

In 1993, the IBM Simon was introduced [51]. This was possibly the world's first smartphone. It was a mobile phone, pager, fax machine, and PDA all rolled into one. It included a calendar, address book, clock, calculator, notepad, e-mail, and a touch screen with a modern-day keyboard layout. The IBM Simon had a stylus used to tap the touch screen. It featured predictive typing that would guess the next characters as you tapped. It had apps, or at least a way to deliver more features by plugging a Personal Computer Memory Card International Association (PCMCIA) 1.8-MB memory card into the phone.

Coinciding with the introduction of 2G systems was a trend away from the larger "brick" phones toward tiny 100–200 g handheld devices. This change was possible not only through technological improvements, such as more advanced batteries and more energy-efficient electronics, but also because of the higher density of cell sites to accommodate increasing use. The latter meant that the average distance transmission from phone to the base station shortened, leading to increased battery life. The personal handy-phone system mobiles and modems was used in Japan around 1997–2003. The 2G phones introduced text messaging and the ability to access media content on mobile phones such as a daily news headline service. The first full Internet service on mobile phones was introduced by the Japanese mobile operator NTT DoCoMo in Japan in 1999.

As the use of 2G phones became more widespread and as a greater number of people started to use phones in their daily lives, it became clear that demand for data (such as access to browse the Internet) was growing. Furthermore, experience from fixed broadband services showed there would also be an increasing demand for greater data speeds. The 2G technology was not up to the job, so the industry began to work on the next generation of technology known as 3G [52]. The main technological difference that distinguished 3G technology from 2G technology was the use of packet switching rather than circuit switching for data transmission. Circuit switching uses a dedicated channel and was primarily developed for voice traffic rather than data traffic. Packet switching breaks up the information into small data packets, and each data package is sent out over the most efficient route. Each data packet may go through different routes from the others. Packet switching has the advantage of security with bandwidth being used to full potential over circuit switching. A circuit switched network is excellent for data that needs a constant link from end to end. The 2G standard was 2 Mb/s maximum data rate indoors and 384 kb/s outdoors.

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During the development of 3G systems, 2.5G systems such as CDMA2000 1x and general packet radio service (GPRS) were developed as extensions to existing 2G networks. These provided some of the features of 3G without fulfilling the promised high data rates or full range of multimedia services. CDMA2000-1X delivered theoretical maximum data speeds of up to 307 kb/s. Just beyond these was the Enhanced Data Rates for GSM Evolution (EDGE) system, which in theory covered the requirements for a 3G system, but is so narrowly above these that any practical system would be sure to fall short. The high connection speeds of 3G technology enabled a transformation in the industry: for the first time, media streaming of radio (and even television) content to 3G handsets became possible, with companies such as Real Networks and Disney among the early pioneers in this type of offering.

Between 2000 and 2010, an evolution of 3G technology, particularly high-speed downlink packet access (HSDPA), began to be implemented. It is an enhanced 3G mobile telephone communications protocol in the high-speed packet access (HSPA) family, also coined 3.5G, 3G+, or turbo 3G, which allows networks based on the universal mobile telecommunications system (UMTS) to have higher data transfer speeds and capacity. Current HSDPA deployments support down-link speeds of 1.8, 3.6, 7.2, and 14.0 Mb/s. Further speed increases are available with HSPA+ with Release 9 of the 3G Partnership Project (3GPP) standards, which provide speeds of up to 42 Mb/s downlink the and 84 Mb/s uplink. This speed improvement was obtained through faster processing and more efficient use of the bandwidth.

By 2009, it had become clear that, at some point, 3G networks would be overwhelmed by the growth

By 2009, it had become clear that, at some point, 3G networks would be overwhelmed by the growth of bandwidth-intensive applications like streaming media.

of bandwidth-intensive applications like streaming media. Consequently, the industry began looking to data-optimized 4G technologies, with the promise of speed improvements up to tenfold over existing 3G technologies. The first two commercially available technologies billed as 4G were the Worldwide Interoperability for Microwave Access (WiMAX) standard (offered in the United States by Sprint) and the long-term evolution (LTE) standard, first offered in Scandinavia by TeliaSonera and in United States by Verizon [53]. By the use of clever coding delivering more bits per hertz than 3G with reduced latency (delay), 4G achieves the increased throughput of date transmission. Figure 13 illustrates the new 4G LTE Apple iPhone 5S featuring the iTouch fingerprint sensor.

Wireless Local Area Network

A wireless local area network (WLAN) links two or more computers without using wires [54]. In 1990, a working group, IEEE 802.11, was formed to define standards for WLANs. In 1997, IEEE 802.11 was released supporting 1–2 Mb/s data rates in the 2.4-GHz ISM band. In 1999, two versions were introduced, IEEE 802.11a and IEEE 802.11b. The IEEE 802.11a supports 1–54 Mb/s in the 5-GHz ISM band while the IEEE 802.11b supports 1–11 Mb/s data rates in the 2.4-GHz industrial, scientific, and medical (ISM) band. In 2009, IEEE 802.11n WLAN protocol was introduced supporting up to 150-Mb/s data rates in both the 2.4-GHz and 5-GHz ISM bands. More details on the various versions of IEEE 802.11 are found in [58].

Figure 13. *4G LTE Apple's iPhone 5S featuring the iTouch fingerprint sensor. (Photo courtesy of Ed Niehenke.)*

Bluetooth Technology

Bluetooth technology was officially introduced in 1998, although it was in development previously in Scandinavia [55]. Both the name "Bluetooth" and the logo associated with it have been trademarked by Bluetooth Special Interest Group (SIG). Bluetooth provides a way to connect and exchange information between devices such as mobile phones, laptops, PCs, printers, digital cameras, and video game consoles over a secure, globally unlicensed short-range RF.

Bluetooth operates in IMS 2.4-GHz short-range RF band. Bluetooth uses a radio technology called "frequency-hopping spread spectrum." The transmitted data is divided into packets and the packets are sequentially transmitted (hopped) among the 79 designated Bluetooth channels. Each channel has a bandwidth of 1 MHz. The first channel starts at 2,402 MHz and continues up to 2,480-MHz in 1-MHz steps. It usually performs 1,600 hops/s, with adaptive frequency hopping (AFH) enabled. Originally, Gaussian frequency-shift keying (GFSK) modulation was the only modulation scheme available; subsequently, since the introduction of Bluetooth 2.0+EDR, $\pi/4$-DQPSK, and 8DPSK modulation may also be used between compatible devices. Devices functioning with GFSK are said to be operating in basic rate (BR) mode where an instantaneous data rate of 1 Mb/s is possible. The term "enhanced data rate (EDR)" is used to describe $\pi/4$-DPSK and 8DPSK schemes, each giving 2 and 3 Mb/s, respectively.

Future Wireless Communications Developments

The following articles in this issue address the status and future wireless communications developments:

- "Handheld Computers" describes the smartphone as not only a voice communication device but also a powerful informing, sensing, and computing platform with accessibility and connectivity of anywhere and anytime.
- "Filling the Spectral Holes" describes receiver architectures to identify unused spectrum and future architectures to operate in those regions.
- "Is There Anybody in There?" describes the detection of human cardiopulmonary motion with Doppler radar, which would provide savings of energy used for lighting and heating, ventilation and air conditioning (HVAC) systems in buildings.
- "The Sky's the Limit" reviews the history of satellite communications with the market trends and technology trends. Current progress and remaining challenges are presented.

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