BIOMONITORING WITH WIRELESS COMMUNICATIONS

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\textbf{Abstract} Wireless biomonitoring, first used in human beings for fetal heart-rate monitoring more than 30 years ago, has now become a technology for remote sensing of patients’ activity, blood pulse pressure, oxygen saturation, internal pressures, orthopedic device loading, and gastrointestinal endoscopy. Technical advances in miniaturization and wireless communications have enabled development of monitoring devices that can be made available for general use by individuals/patients and caregivers. New methods for short-range wireless communications not encumbered by radio spectrum restrictions (e.g., ultra-wideband) will enable applications of wireless monitoring without interference in ambulatory subjects, in home care, and in hospitals.

\textbf{CONTENTS}

INTRODUCTION .................................................. 384
PHYSIOLOGIC MONITORING SYSTEMS .......................... 385
\hspace{1em} Heart-Rate Monitoring .................................... 385
\hspace{1em} Blood Pressure ............................................ 387
\hspace{1em} Blood Oxygenation/Pulse Oximetry ...................... 389
\hspace{1em} Carbon Dioxide Partial Pressure ............................ 390
\hspace{1em} Pulse Transit Time ............................................ 391
\hspace{1em} Pulse Transit Time Respiratory Monitoring ............... 392
PHYSICAL ACTIVITY MONITORING ............................ 393
\hspace{1em} Fall Detection ................................................ 394
\hspace{1em} Locator or Tracking Monitors .............................. 395
\hspace{1em} Wireless Intracorporal Pressure Monitoring ............... 395
\hspace{1em} Gastrointestinal Radiotelemetry ............................ 397
\hspace{1em} Wireless Musculoskeletal Monitoring .................... 398
COMMUNICATIONS ........................................... 398
\hspace{1em} Wireless Frequencies ..................................... 398
INTRODUCTION

This is a review of technologies for monitoring physiological parameters that have been or can be integrated with wireless communications methods including human and radiological image transmissions. Applications range from monitoring high-risk patients for heart and respiratory activity and falls to sensing levels of physical activity in military, rescue, and sports personnel. The range of measurements include heart rate, pulse waveform, respiratory rate, blood oxygen saturation, tissue pCO2, exhaled carbon dioxide, physical activity, strain in orthopedic devices, intracorporal pressure, and gastrointestinal lumen visualization. As early as 1957, wireless communications technologies were used for measuring pH and temperature from internal cavities using the then new technology of the transistor (1, 2). Reviews of the work in the late 1950s and 1960s on wireless telemetry from subcutaneous and deep-body sites (in animals) showed the promise and some technology limitations of telemetry (3–5). In the 1970s, measurements from human subjects were shown to be feasible for fetal monitoring in utero (6–8) for electrocardiogram (ECG) telemetry (9) and gastrointestinal pressures (10). Although the feasibility of using wireless technology to communicate vital signs was demonstrated more than 30 years ago, only recently have practical and portable devices and communications networks become generally available for inexpensive deployment of comfortable and affordable devices and systems, the most recent of which is the wireless endoscope (11). Further technology developments in wireless technologies have enabled applications of wireless monitoring, which until recently were restricted by radiofrequency interference concerns.

Although the focus of this review is on biomonitors and wireless communications, one should not neglect the substantial background technology for bedside monitoring of chronic and acute status by well-known devices. Common measurements include ECG, temperature, blood pressure, oxygen saturation, and respiratory rate. Some of these systems have wireless modules, but the development of local area networks (LAN) in hospitals has not matured. The performance of these systems has been under comparative review, as found in the periodical Health Devices (12). Representative in-hospital monitoring devices can be found on websites for Medtronic (http://www.medtronic.com), Nellcor (http://www.nellcor.com), Hewlett Packard (http://www.hp.com), and Guidant (http://www.guidant.com).
The major bioengineering emphasis of this review concerns the interface between human physiology and sensors and wireless telemedicine. Engineering directed toward electronic integration of the sensors for wireless communication is presented by Jovanov and coworkers (13) and Drewes and coworkers (14), following early work by several groups (8, 15–25).

**PHYSIOLOGIC MONITORING SYSTEMS**

The variety of sensors that meet the criteria of noninvasiveness, comfort, and medical usefulness are summarized in Figure 1. Not all of these monitoring devices or ideas have been reduced to practical devices, but those that are not available are either currently being researched or have promise from an engineering perspective.

**Heart-Rate Monitoring**

Heart-rate or pulse-rate monitoring can be accomplished by a number of methods, some of which are appropriate for nonelectrode-based wireless communications.

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**Biomonitoring**

A. Chemistry chip pendant  
(saliva sampling)

B. Skin electrodes  
(cardiac & respiratory)

C. Strain guage & heart-rate monitor

D. Accelerometer

E. Phone /camera / GPS

F. Chemistry  
(PO2, PCO2, sugar)

G. Local area network

H. Pulse pressure

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Figure 1  Synopsis of portable, noninvasive, and easily worn monitoring systems with wireless potentials.
These methods include (a) wireless heart-rate chest strap, (b) electrical waveform (ECG), (c) pulse oximeter, (d) ultrasound Doppler, (e) pulse pressure detection by strain gauge impedance or piezoelectric volume change, and (f) electromagnetic flow. The earliest investigation of wireless heart rate probably used the surface electrode detection of electric potential changes from taped-on electrodes (9).

The most frequently used method by athletes and individuals in exercise conditioning programs is the chest-strap monitor, which transmits the heart-rate signals collected across the chest by a electrode that picks up the potential differences [e.g., Nordic Track (www.nordictrack.com)]. The signal is detected within 2 m by a wrist-mounted device, which also serves as a timepiece. Electronic receivers in exercise equipment (e.g., treadmills, bicycles) also detect these signals.

Reviews of most of these methods of heart-rate monitoring are found in the book Medical Instrumentation: Application and Design (26) and the Biomedical Engineering Handbook (27). In addition to pulse rate, these methods provide important information regarding their respective waveforms. All methods give heart rate, but the information obtainable from the pressure pulse and the ECG are sufficiently different, such that innovations that allow convenient acquisition of these data might prove to be very valuable even in monitoring non-high-risk subjects (e.g., those recovering from illnesses or patients undergoing recuperative chemical therapies). Figure 2 diagrams these differences as well as how a combination of the two methods can give pulse transit time (PTT) information (discussed below).

One of the earliest clinical examples of wireless medical telemetry is fetal heart-rate and intrauterine pressure monitoring by probes inserted into the uterus.

Figure 2 Signals from the ECG and pulse pressure changes provide different physiologic information and can be used together to gain additional data such as the pulse transit time (PTT). Rapid pulse timing can be from a pulse pressure monitor or from a pulse oximeter in the reflectance mode or conventional transmission mode.
with a two-channel miniature radio transmitter. Signals detected by a receiver at
distances up to 10 m allow wireless monitoring (6). This type of monitoring is
in current practice with wired connections to modern bedside equipment. Indeed,
hard-wired systems in hospital environments are the practice, and wireless connec-
tions in intensive or critical care situations within the local hospital environment
need to be engineered such that electromagnetic interferences are removed. The
advantage and potential of taped-on ECG electrode-transmitter systems for ECG
measurements were recognized in 1971 when the first human studies of this method
and wireless temperature sensing were reported (28). These advantages include
elimination of interference of ECG monitoring from other wired systems, ability
to monitor adults and infants in isolated settings including incubators, chronic
monitoring of high-risk patients using a portable monitor or data recorder, and
elimination of electrical hazards.

But when wiring beds in a hospital ward is awkward, wireless systems to a LAN
have been shown to be effective (29). Of course, beyond the critical care nurses
stations, there is a major problem of communicating, to the cardiologist or other
caregivers, data such as ECG, intrauterine pressure curves during contractions,
oxgen saturation, and other parameters that cannot be reliably communicated by
voice to physicians. It is the flexible and accurate communication remote from the
bedside that requires a robust communications network. Outside the hospital, a
number of systems have shown successful operations recently. Examples are ECG
consultation with cardiologists using pocket wireless computers (30) and a home-
based system for cardio-respiratory monitoring of elderly or ill patients (31). Be-
yond the home and hospital environments, that is, in space or environments remote
from cosmopolitan networks, there have been remarkable successes, as evidenced
by the Mt. Everest experiment (32), the commercial airline ECG transmission ex-
periment (33), and the recent simulation of a Mars medical data communication
link from the Arctic remote environment (34, 35).

**Blood Pressure**

An estimated 50 million Americans, which is about 25% of all adults, have high
blood pressure. But over 30%, or 15 million Americans, are not aware of their con-
dition. There are five noninvasive methods of measuring blood pressure: (a) aus-
cultation, (b) palpation, (c) flush, (d) oscillation, and (e) transcutaneous Doppler.
The characteristics and limitations of each method are discussed in Reference 36.
All five methods require nanometric observations of applied pressure versus some
measure of flow change. Of the five methods, the oscillometric and transcutaneous
Doppler can allow remote monitoring by incorporation of sensors for pressure os-
cillations or Doppler shift in the pressure cuff around the wrist or finger of humans
and around other sites in animals (e.g., tail or leg).

A single blood-pressure measurement in the doctor’s office or clinic is usually on
the high side and frequently written off as the “white coat” effect. The true impact
of hypertension on the vascular system requires monitoring, as frequent excursions
of the systolic and diastolic blood pressure can be expected to injure the endothelial cells of the arteries, and this injury can lead to atherosclerosis. The importance of a portable blood-pressure monitor is based on the need to evaluate the presence or absence of hypertension, particularly in subjects who manifest the white coat phenomenon of elevated blood pressure when taken in the clinic and those patients who have the reverse white coat phenomenon of a relaxed physiology when in the protection of doctors and nurses in the clinic. There is an increasing interest in patients with variable blood pressure and a recognition that monitoring blood pressure during a typical day is needed in patients being evaluated for blood-pressure elevation and in patients whose blood-pressure treatment is being optimized. Automation of these measurements by a device such as that shown in Figure 3 can include on-board time data logging for subsequent docking and readout. Possibly, a more acceptable mode is to use a LAN for recording the data by using wireless transmissions through a cell phone or a belt-mounted device, and from there transferring the data to a central repository for evaluation by the caregiver.

Brachial artery blood-pressure monitoring using wireless telemetry has recently become available (www.welchAllyn.com, www.Nellcor.com), and the demand for 24-h monitoring of subjects with suspected hypertension could be made practical and acceptable to patients if a light-weight system with wireless readout to a LAN, such as the one suggested below, is made available.

Currently, the most portable, user-friendly blood pressure measurement device is a wrist- or finger-applied monitor marketed by OMRON Inc. (www.omron.com) and shown in Figure 3. These units have a 14-memory storage feature that makes recording measurements easy. They are powered on two AAA batteries and can measure blood pressure and pulse. The wrist cuff automatically inflates and deflates, and these devices have been proven clinically accurate, but wireless telemetry has not been incorporated.

Figure 3 Illustration of a self-contained, wrist-worn blood pressure device similar to that marketed by OMRON Inc. (~$75 US).
One can argue that the home-care potential of these devices will reach full potential when the information can be recorded remotely and transmitted to caregivers through LAN wireless systems.

**Blood Oxygenation/Pulse Oximetry**

Tissue oxygen saturation as reflected in the amount of oxyhemoglobin in the circulating blood. Oxygen level is a variable of major importance for acute patient monitoring in the hospital, at the scene of accidents, and in effective subacute monitoring for home care. The simplest method is pulse oximetry, whereby the differential absorbency of light through the capillary bed of the ear lobe or finger tip can give a reasonably reliable parameter that allows continuous monitoring. Most systems are for bedside monitoring [e.g., Nellcor (www.Nellcor.com) and Welch Allyn (www.monitoring.welchallyn.com)], and there has been little demand for miniature portable systems, though one can predict portable wireless systems will have a place in monitoring infants and others on oxygen and those with sleep apnea.

The measurement is performed at two specific wavelengths: a wavelength of about 660 nm where there is a large difference in light absorbance between Hb and HbO\(_2\), and a second wavelength typically chosen between 805 and 960 nm in the near infrared region. Around 805 nm, the absorbance of light is about equal for Hb and HbO\(_2\). A measurement of the percent oxygen saturation of blood in vitro is made by comparing the log of the transmitted light power to emitted light power or the optical densities at the two wavelengths. A measurement in vivo must take into account the light absorption by the venous blood and the bloodless tissues. This is accomplished by comparing the AC optical densities to the DC densities over the two wavelengths. These densities are determined from the time versus transmitted light signals obtained by rapidly pulsing light at the two successive wavelengths during the cardiac cycles, thus the name pulse oximeter.

The pulse oximetry signal is caused by changes in arterial blood volume associated with each heart beat. The magnitude of this signal depends on the amount of blood pulsing into the peripheral vascular bed; the optical absorption of the blood, skin, and tissue; and the wavelength used to illuminate the blood. Electronic circuits separate signals from the two wavelengths into pulsatile (AC) and nonpulsatile (DC) signal components. An algorithm inside the pulse oximeter performs a mathematical normalization by which the AC signal at each wavelength is divided by the corresponding DC component. The DC component is related to absorption by the bloodless tissue, residual arterial blood when the heart is in diastole, venous blood, and skin pigmentation. Because it is assumed that the AC portion of the photoplethysmogram results only from the arterial blood component, this scaling process provides a normalized red/infrared ratio, R, which is highly dependent on the color of the arterial blood, but is largely independent of the volume of arterial blood entering the tissue during systole, skin pigmentation, skin thickness, and vascular structure. Therefore, the instrument does not need to be recalibrated for measurements on different patients.
A wrist-worn pulse oximeter engineered by Minolta is shown in Figure 4. This system measures both pulse rate and blood oxygen saturation with an accuracy of \( \sim 2\% \). The readout is a back-lighted display from the finger-tip sensor. This is probably the smallest portable commercial system with a battery life of 48 h (two AAAs) and mass of 42 g. Recently, a wireless system has been advertised for a multiparameter portable monitor (www.WelchAllyn.com), but that monitor is too large to be worn. The device in Figure 4 does provide a platform for collecting data that can be sent conveniently through a wireless LAN, either directly to repeaters in the hospital or home environment or indirectly via the person’s on-board LAN.

Highly precise arterial oxygen saturation (\( \text{SaO}_2 \)) measurements are commonly obtained using transmittance pulse oximeters in clinical situations (37). The application site of the transmission pulse oximeters is limited mainly to the peripheral tissue, such as the fingertip, ear lobe, or toe, from which the transmitted light can be detected. Alternately, a reflectance oximeter can measure \( \text{SaO}_2 \) from various parts of the body, especially from other body regions such as the forehead, cheek, wrist, etc. With the reflectance oximeter, the wavelength combination, 730/880 nm, was determined to obtain a linear relationship between the reflectance ratio and the broader \( \text{SaO}_2 \) range from 100% to 30% in comparison to the 660/910 nm wavelengths of conventional systems (38). The reflection pulse oximeter sensor can be applied to various locations of the body in the hospital and home health care scenarios to aid in the early diagnosis of cardiopulmonary as well as peripheral circulatory disorders.

A recent comparison of 20 pulse oximeters showed some with superior performance under patient motion conditions. The information conveyed by pulse oximeter and pulse pressure waveform have not been combined in an interpretable fashion, though the potential value of combining these data has been suggested (39).

**Carbon Dioxide Partial Pressure**

Measurement of pCO\(_2\) on the human skin surface was first described by Severinghaus in 1960 (40). Transcutaneous partial pressure of CO\(_2\) can be measured by a portable system (41) similar to that diagrammed in Figure 5. The CO\(_2\) sensor is a glass pH electrode with a concentric Ag/AgCl reference electrode that is used
as a heating element. The electrolyte, a bicarbonate buffer, is placed on the electrode surface. A CO₂-permeable Teflon membrane separates the sensor from its environment.

The transcutaneous pCO₂ sensor operates according to the Stow-Severinghaus principle, that is, a pH electrode senses a change in the CO₂ concentration. This system is calibrated with a known CO₂ concentration solution. Heating the skin beneath the sensor causes an increase in measured (a) pCO₂ because the solubility of CO₂ in tissue decreases with an increase in temperature; (b) local tissue metabolism because cell metabolism is directly correlated with temperature; and (c) the rate of CO₂ transit through the stratum corneum, which increases with temperature.

As a consequence of these three effects, which all work in the same direction to increase transcutaneous pCO₂ values, heating the skin yields pCO₂ values larger than the corresponding arterial pCO₂. Nevertheless, the correlation between transcutaneous pCO₂ and arterial pCO₂ is usually satisfactory. Because the slope of the CO₂ electrode calibration line is essentially that of the Nernst equation, a two-point calibration is not needed (42). Transcutaneous pCO₂ sensors have responses on the order of minutes that depend on the induced skin temperature, with a required time of 3.5 min for the maximum temperature of 44°C one would reasonably achieve (43). A comparison of direct end-tidal gas PaCO₂ to the transcutaneous method relative to arterial PaCO₂ showed superior performance of the transcutaneous method (44).

**Pulse Transit Time**

PTT refers to the time it takes a pulse wave to travel between two arterial sites. The speed at which this arterial pressure wave travels is inversely proportional to vascular compliance, and because there is a direct relationship between vascular tone stiffening and acute rises in blood pressure, PTT decreases are proportional to blood pressure increases. Conversely, when blood pressure falls, vascular tone decreases and PTT increases.

The importance of measurements of the PTT lies in the fact that the vascular relaxivity is intimately related to cardiovascular disease. The relationship between
a decline in relaxivity or a decrease in the compliance of the vascular system and atherosclerosis is believed to be related to the function of the endothelial system and therefore to atherosclerosis. A diminution in the difference between the arrival of a pulse at the brachial artery versus the ankle or in the difference between the R-wave time and the radial artery pulse arrival would be expected to indicate a stiffening of the vascular system, which could be due to momentary changes in the sympathetic system or due to pathology of the vascular system. It is now well known that the arterial compliance of some and perhaps most individuals will change in response to dietary intake and emotional state. One of the major areas of focus in studies of atherosclerosis is endothelial cell function, and one of the simplest measurements of endothelial cell function is the PTT change over time and under conditions of changes in blood flow.

Originally, PTT was measured by recording the time interval between the passage of the arterial pulse wave at two consecutive sites. More recently, for ease of measurement, the electrocardiographic R or Q wave has been used as the starting point, as it corresponds approximately to the opening of the aortic valve (Figure 2). The interval between the R wave and the arrival of the pulse wave, generated using photo-plethysmography, at a peripheral site, such as the finger, is the PTT (Figure 2). Using ECG leads and finger photo-plethysmography, reproducible PTT measurements can be made very simply. Two classes of measurements applicable to health care are sleep apnea monitoring and assessment of vascular relaxivity or compliance.

There is currently a need to simplify tests used in the investigation of patients with suspected sleep-disturbed breathing without necessarily compromising the accuracy of these data. The capability of PTT to identify and semiquantitatively measure respiratory effort has been established (45–47). Beta-sympathetic and parasympathetic stimuli influence pulse transit time, and a convenient measurement system may have important clinical application in the evaluation of the sympathetic/parasympathetic systems (48).

The current methods of measuring PTT are awkward and require a second person. Telemetry would enable this measurement, as the timing of the ECG signal from a simple chest strap, used in wireless pulse monitoring relative to the arrival of a pulse detected by pulse oximetry or a miniature Doppler device on the wrist or ankle, would be facilitated by the wireless signals.

Pulse Transit Time Respiratory Monitoring

One of the first successful deployments of a wireless breathing monitor is the radio transmitter/receiver system for monitoring breathing and other sounds of infants in the home. These systems operate at 900 MHz and give reliable communications within ranges of 30 m at affordable prices of ∼$60 (e.g., www.babyuniverse.com).

The major motivation for the development of monitoring systems for breathing has been preventative medicine for sudden infant death syndrome (SIDS), which appears to be related to apnea. Respiration patterns are currently measured by direct
wire techniques, which are awkward for infants and patients having multiple input and sensor lines attached.

The combination of respiratory monitor and wireless technologies is embodied in a commercially available cardiorespiratory monitor working with field plethysmography, wireless signal transmission, and an alarm system (SpiroGuard C). In order to determine the recognition rates for central, mixed, and obstructive apneas, a prospective clinical trial was performed comparing the frequency and pattern of signals from the monitor with those simultaneously registered by polysomnographic studies. Approximately half of the alarms were false alarms. These could be reduced by setting the apnea detection time to >15 s, by tighter fastening of the respiration belt (improving the signal transmission), and by turning off the instrument when the child was awake and physically active. The wireless system renders the SpiroGuard C an attractive alternative for home monitoring (49).

A device for infant monitoring of multiple parameters has been developed for the Collaborative Home Infant Monitoring Evaluation (CHIME). This monitor measures infant breathing by respiratory inductance plethysmography and transthoracic impedance; infant electrocardiogram, heart rate, and R-R interval; hemoglobin O₂ saturation of arterial blood at the periphery; and sleep position. The monitor was considered to be superior to conventional monitors and, therefore, suitable for the successful conduct of the CHIME study (7, 50). Another trial using a home-based telemetry system showed accurate transmission of cardiorespiratory data compared to data taken by trained medical attendants (26).

As ultra-wideband technology has been released for unlicensed applications, one can expect in-mattress devices, which would monitor infant breathing by chest excursions using a radar mode for detection and a telemetry mode for parent monitoring and alarm systems.

**PHYSICAL ACTIVITY MONITORING**

Sleep research objectives have motivated the development of accelerometer-based systems for measuring an individual’s movements. These systems, developed approximately 15 years ago, are based on piezoelectric or capacitance change accelerometers with reliable performance even with only one-dimensional capability. The devices are known as “actigraphs” and can be commercially acquired from a number of companies (e.g., Ambulatory Monitoring, Inc., New York; iLifesystems, Oregon). These devices are currently used for monitoring the activity of patients and are being promoted as an accessory for the general population interested in having a metric of their exercise activity. The devices can be worn on the wrist or elsewhere, such as the belt. A drawing of two types of these devices is shown in Figure 6. Although the implementation of wireless communication using the wrist-mounted device is only on the drawing board at present, the wireless communication of information from the larger belt-worn system to a local LAN is part of a current product. The watch readout is wireless through LED communication.
Figure 6  General concept of a wearable accelerometer or motion detector, which allows continuous monitoring of a subject’s daily activity as well as detection of a fall. Wireless communication of information can be stored in a local network node, or the belt-worn transmitter can be used to transmit alert signals or as a relay for actual data.

Although manufactures claim that one-dimensional accelerometers are adequate, a three-axis system would be required for truly representative data for integrating physical activity and accurate fall detection. The pedometer is a good example of a one-dimensional activity monitor and is not of much use if it is oriented 90° from the up and down motion of walking.

Fall Detection

Devices that allow patients at risk for cardiac events to call for help have been developed with wireless communication capabilities to a home-based LAN through “burglar alarm”–type communication to a commercial server. These devices serve a patient in distress but also have a major role in fall detection, as falls are the leading cause of death by injury for people over 65 years old. Overall, 33% of people aged 65 and over will have a fall according to the National Safety Council, and in the lifetimes of these individuals, one third will eventually be disabled or killed by a fall. A remarkable further statistic is that at least 300,000 people are found dead or helpless in their own homes in the United States every year, and approximately 10% of people who fall at home are on the floor for more than one hour (51). To meet this problem, industry has developed panic button or alert systems that depend on the home LAN for secure communications to a response center just as one would communicate a burglar entry or fire by a wireless network in the home. One of these systems, known as HealthSensor 100 (Framingham, MA), uses a voice communicator that links the patient or person in need to the response center. Another such system is called Lifeline and is located in Framingham, Massachusetts. Two-way speakerphone capability allows communication between the patient and personnel at the call center. Panic buttons on a necklace or wrist-worn device send an alarm that can be reset or cancelled; however, if not reset or cancelled, the system will activate a telephone communications between patient and communications central. These systems require monthly costs and are not scalable to widespread communication networks.

The Australia Commonwealth Scientific and Industrial Research Organization (CSIRO) has fielded a project called Hospital Without Walls, which aims to provide continuous monitoring of patients in certain diagnostic categories (52). The key
technology is a miniature, wearable, low-power radio that can transmit vital signs and activity information to a home computer, from which data may be sent by telephone line and the Internet to appropriate medical professionals. Accelerometers and radio transmitters worn on the patient use LAN to relay activity and characterize falls. Simultaneous measurement of heart rate can provide information about abnormalities of cardiovascular physiology at the time of a fall.

Web sites relevant to fall alerts and panic button communications are: (a) http://www.americanmedicalalarms.com, (b) http://www.ilifesystems.com, (c) http://www.lifealert.com, and (d) http://www.seniorsafety.com.

Locator or Tracking Monitors

In the past six years, a number of commercial devices have become available for the tracking of patients (e.g., Alzheimer’s patients), children, pets, and lost outdoor adventurers including skiers. The oldest system is WorldTrack (http://www.eworldtrack.com), which is designed to give the family, custodian, and emergency/medical personnel a wireless system for locating individuals who have an on-board global positioning system (GPS) receiver and a communication system to their own network. Other systems are to be offered to the public by Siemens AG and Applied Digital Solutions (http://www.digitalangel.net). Tracking can be done by the concerned family member via the Internet. Of course, there is a monthly fee for maintaining this service, but other than the access to the Internet, the equipment needed requires less than $700 investment for the on-board communication device. An alternative approach that could be deployed without reliance on commercial vendors is shown in Figure 7.

For major emergency distress in remote places, a wristwatch with a reasonably long-range beacon has been offered by Breitling (Figure 8). On flat terrain or calm seas, the transmitter’s signal on the 121.5-MHz aircraft-emergency frequency has a range of about 160 km (100 miles), assuming the search craft is flying at 6,000 m (about 20,000 ft). But the expense of an accurate wristwatch could be removed, and a matchbox-sized emergency transmitter or beacon developed for an online deployment by rescue workers and other personnel at remote sites (e.g., skiers) could be developed using ultra-wideband technologies (but see infra). Short-range wireless locator devices for mountaineers and skiers cost about $250 and weigh less than 0.25 kg with limited ranges of 30 cm (but see http://www.mooremfg.com).

Use of home or personal monitoring systems, including fall alerts, poses some safety problems. The implications of any failure of a technology on which patients or caregivers rely must be addressed in order to provide a safe and reliable care service. This topic has been reviewed relative to procedures for risk assessment (53).

Wireless Intracorporal Pressure Monitoring

Though the first deployment of a short-range wireless system in human beings was for monitoring intrauterine pressure (6), wired systems are adequate for moderate or high-risk delivery situations. However, this is not the case for cerebral pressure monitoring in multiple-bed wards and with ambulatory patients where
Figure 7  A customized tracking system for a private automobile or a wander-dering family member can be a major household appliance but currently relies on HAM radio licensed operations.

Figure 8  Designed for pilots and air crews, this Breitling watch has a built-in micro-transmitter that is activated by unscrewing a protective cap and pulling the antenna out fully. The system will broadcast a 121.5-MHz emergency frequency for 48 h.
hydrocephalus problems are being chronically treated. Indeed, some of the earli-
est (ca. 1980) applications of wireless monitoring were for intracranial pressures,
dating from 1976 (54–58). A fully implantable device for measuring intracorporal
pressure and temperature under normal conditions, consisting of a sensor element
combined with a transcutaneous telemetric interface, has been suggested (59).

Gastrointestinal Radiotelemetry

Wireless technologies have been described or used for gastrointestinal monitoring
of pressures (10, 60, 61), pH (62), temperature (63), and radiation (64). A new
development is the use of a capsule-camera for endoscopy. Given Imaging Ltd. has
developed a wireless imaging system, known as the M2A capsule, for examination
of the gastrointestinal tract (65, 66). The system uses a miniaturized video camera
contained in a disposable capsule that is ingested by the patient and delivers color
images in a painless and noninvasive manner (Figure 9). The system employs a
series of eight antennae pickups that are attached to the torso. These feed signals
to an on-board recorder in a belt. The data are downloaded to an analysis unit that
allows viewing single images and short video strips taken at 2-s intervals during
the capsules transit through the gut. As many as 50,000 images are acquired.
Information on the location of the capsule is also decoded (67). Food and Drug
Administration (FDA) approval was obtained for use of the M2A system as an
adjunctive tool in detecting abnormalities of the small intestine. This system has

![Figure 9](wireless_endoscopy.png)

*Figure 9* Wireless endoscopy using a disposable self-contained camera in an
available capsule (11 mm × 26 mm) that is tracked by an antennae array fastened
to the torso (Given Imaging Ltd., [http://www.givenimaging.com/usa](http://www.givenimaging.com/usa)).
been the subject of a number of clinical trials in the last three years, with impressive
detection statistics when compared to conventional endoscopy (68–73).

**Wireless Musculoskeletal Monitoring**

One of the first applications of telemetry was muscle–action potential measurement
using an implanted system in animals (14). Extensive clinical experience has been
built up using orthopaedic implants instrumented with strain gauges connected to
a Wheatstone bridge by means of percutaneous leads. This research showed that
monitoring the deformation of implants provides a powerful tool to evaluate nurs-
ing and rehabilitation exercises, for tracking dangerous overloads and anticipating
implant failure, and also to observe the healing process (74).

An integrated eight-channel telemetry chip was specially developed to measure
the signals of six strain gauge sensors, the temperature of the implant, and the
supply voltage. Because the internal fixation devices are always implanted in
pairs, two telemetry units are operated at the same time. A Dick internal fixation
device was modified and outfitted with a hermetically sealed inductively powered
telemetry unit in order to measure the forces and moments within the implant (75).

**COMMUNICATIONS**

**Wireless Frequencies**

The three methods of wireless transmission to be considered in transmitting bio-
monitor information are radio-frequency electromagnetic signals, infrared optical
signals, and acoustic signals. The main focus of most wireless transmission is RF
(electromagnetic or radio frequency), but optical data transmission can be efficient
and interference proof in some applications [e.g., early work by Kimmich (76)].
Acoustic transmission of data over phone lines from ECG data devices has shown
some application (77), and through-water communications of physiological signals
have been demonstrated (78); this mode is not discussed further in this review.

The range of frequencies used for electromagnetic wireless communications are
from 121 MHz, used in the Breitling wrist watch emergency beacon transmitter
(Figure 8), to 2.5 GHz, commonly used in short-range LAN. Common frequencies
for HAM radio are 141 MHz (2-m wavelength) and 400 MHz (ca. 70-cm wave-
length). Cellular phone frequencies are in the 900-MHz (~30-cm wavelength),
1800-MHz, and 1900-MHz bands.

Two Federal Communications Commission (FCC)–prescribed frequency bands
have been available for medical telemetry. The VHF (174–216 MHz) spans TV
channels 7–13, and medical telemetry can use frequencies not used by TV. The
medical UHF band (450–470 MHz) is below the UHF TV band, but medical
telemetry is permitted only on a secondary basis to private and land mobile radio
services, such as emergency vehicles using high, transmitter-powered commu-
nication frequencies. A secondary user cannot interfere with the primary emergency
mobile units and the secondary user must tolerate the interference from those services. The inadequacy of these bands became clear with the introduction of digital television, which occupies both VHF and UHF frequencies. For the newly unlicensed band, see ultra-wideband discussion below.

Practical LANs are not limited by the FCC-prescribed frequency bands but are subject to interference from noise (e.g., cell phones), transmission coverage, and multipath data blurring. Below, some advantages of multiple-frequency systems are discussed using both 2.5-GHz and 4XX-MHz frequencies.

One of the commercial devices appropriate for ambulatory monitoring of ECG and blood oxygenation through pulse oximetry is the Guardian Telemetry Transmitter Model 20601, which transmits in the 450–470-MHz range and costs about $2500. Improved models through miniaturization and alternative methods of acquiring heart-rate and pulse waveforms using a personal LAN can be expected for these higher transmitter–power ambulatory devices.

Demonstration of the global capabilities of wireless communication of vital sign information was an experiment from an airborne Boeing 757 to three remote locations on the ground (47). Because all recipient stations relied on an institutional network to receive the information, it was not possible to transfer data to a given location beyond the hospital campus. This limitation can be overcome using Wireless Application Protocol (WAP) technology for the Internet. Cellular Digital Packet Data (CDPD) protocols enabled data transfer speeds up to 19,200 bps to a digital cellular phone (G2). Medical data that included blood pressure, pulse, respiratory rate, end-tidal CO2, oxygen saturation, and ECG tracings were transferred from a 2G (digital cellular) linked to a hand-held computer.

**RF Transponders**

Most systems are deployed using simplex reporting radio that requires minimum on-board battery drain. An advance beyond these systems is a duplex device that can be controlled remotely so that an individual’s status can be interrogated by querying the on-board central processor unit for data in order to download, set sensitivity, deploy filters, or engage alternate biosensors available on or implanted in the patient. An example of a duplex system operating at 2.45 GHz using a hospital LAN depends on a transponder uplink (base station to patient) with 2.45 GHz selected as the interrogating frequency and 418 MHz as the downlink (patient to base) for sending biosignals. The downlink uses well-established surface acoustic wave (SAW) resonator circuitry (80).

System requirements for selection of the optimal frequencies for wireless biomonitoring necessitate evaluation of the tradeoffs between ambient noise frequencies, antenna size, efficiency and polarization, effective reliable communication distances, and power available for interrupted or continuous monitoring (29, 81, 82). Transmission of downlink signals at 418 MHz has advantages because the keying rates up to 20 kbps are available, which would allow digital waveform signals to be transmitted (RF Monolithics Inc., Dallas, TX). Transmission
of the interrogating or uplink message offers advantages of low levels of man-made noise, wide bandwidth, ease of directional antenna deployment, and potentially higher antenna efficiencies compared to lower UHF and VHF bands. Recall that a $1/4$ wavelength–efficient antenna for 2.45 GHz is 3 cm versus 18 cm for 418 MHz.

Wireless Technologies Applicable to Short-Range Biomonitoring Applications

Promising new wireless short-range systems that are designed to provide wire-replacement that is virtually transparent to the user have taken advantage of the license-free 2.45-GHz ISM band in both North America and Europe. There are two systems currently using this band. The Home RF Working Group is a group of major computer and wireless companies that established an open industry specification for wireless digital communication between personal computers and consumer electronic devices where distances for communication are generally less than 30 m. This group set up the shared wireless access protocol (SWAP), whose major application is setting up a home or office network that connects computers with peripherals for the purposes of sharing files; printers; and other electronic devices, including modems and telephones. SWAP could be used for biomonitoring communications in the home environment.

Bluetooth is a wireless technology with somewhat similar objectives to those of SWAP. It was developed by member companies of the Bluetooth Special Interest group led by Ericsson, IBM, Intel, and Nokia. The heart of the Bluetooth technology is a small microchip ($9\text{ mm} \times 9\text{ mm}$) that contains radio circuits and protocol software. This chip uses a spread spectrum, frequency hopping, full duplex signal at up to 1600 hops/s. Bluetooth’s objective is to make connections with sensors to portable devices or connections between portable devices, whereas SWAP is a low-cost wireless local network for the home, hospital ward, office, and similar environments.

Both SWAP and Bluetooth protocols are derived in part from the IEEE 802.11 specifications for wireless LAN. The systems are not mutually compatible and can interfere with each other. The bioengineer interested in wireless applications can find an entry into the Bluetooth community through the website (http://www.bluetooth.com).

Higher-frequency systems for short-range communications in the United States will employ the recently allowed 5.7-GHz frequency band and the already developed high-performance radio LAN (HIPERLAN) in Europe. This system operates from 5.15 to 5.25 GHz with three transmit power classes: 10, 100, and 1000 mW. The indoor range is from 35 to 50 m. The expectation is that the HIPERLAN-based systems will be approved for use worldwide. It is license exempt in Europe and the U.S. FCC has now allocated a compatible spectrum for similar applications.

Ultra-wideband (UWB) is a new technology that uses very narrow time pulses at low repetition rates. The transmissions are not detected by ordinary radio receivers and thus can exist without interference from existing devices. The center frequency covers the range of around 0.6 to 5 MHz. Pulses are transmitted according to a
predetermined code, and as a multiple-coded system, it could be used in a manner similar to CDMA cellular networks. The virtues of the UWB technology include multipath, interference immunity, simple electronics, and ranges up to kilometers with submilliwatt average power levels. Applications range from all those of this review and include lost personal items, including lost golf balls on golf courses. But adoption of this technology has been limited until a recent ruling by the FCC, which allows unlicensed operations of time-hopping technologies. As of spring 2003, the FCC affirmed its approval of unlicensed operations as an amendment of Part 15 of this legislation after about five years of evaluations regarding interference with GPS and radio communications activities of the government. Devices must be operated in the frequency band ranging 3.1–10.6 GHz. The approval even extends to a possible medical imaging system, which may be used for a variety of health applications to “see” inside the body of a person or animal. Operation must be at the direction of or under the supervision of a licensed health care practitioner. Other applications, such as monitoring baby breathing, are also allowed as long as they are indoors. This FCC ruling will allow UWB implementation that could lead to major developments in biomonitoring not only in the home and large hospital environments, but also to ambulatory monitoring with convenient connection to the Internet. Some fundamental aspects of modern short-range wireless technology can be found in (83), and for UWB, in (84).

Communications Beyond the Lan

Once the data have reached a downlink node, the signals can now be moved to multiple noise impervious and nonlossy hardwire links, such as the Internet, phone lines into caregivers stations, rescue worker stations, or concerned friends and family. Transmissions from sensor to modems to telephone systems and then to FAX hard copy is a mode useful for two-dimensional signals, such as 12-lead ECG or images. Somewhat more flexible yet less reliable receivers are cell phones, pocket wireless, or palm computers. These modes are illustrated in Figure 10.

CDPD is a wireless data communication protocol that uses the existing cellular network, allowing the user to send and receive data wherever there is cellular coverage. CDPD is designed to be integrated into any network. CDPD and the current cellular voice network are essentially two separate networks that happen to share cellular air space. Cellular voice channels are statistically idle 30% of the time even during heavy traffic times. CDPD uses these wasted moments, making the cellular network more efficient while remaining transparent to the cellular voice network. CDPD sends a packet of data on however many possible open channels. Additional data may come on another channel that becomes available. Data received may come on a channel the sender just used or some other channel in small packets. A user-specific IP virtually connects the user indefinitely to the host without interrupting cellular phone communications.

An aspect of wireless telecommunication allowing caregivers visual, voice, and data communication with patients and health care systems is the development of a wearable personal computer (PC). One proposed system has a core technology
Figure 10 Multimodal communication of medical information for improving availability to caregivers and medical consultants is evolving in step with improvements in technologies. At the left is shown a consultant encumbered with multimodal communications. At the right is shown the current capability of hand-held communication devices for viewing data as well as radiologic images.

based upon a wearable PC with a smart-card interface coupled with speech, pen, video input, and wireless Internet connectivity. The TransPAC system with the MedLink software system is designed to provide an integrated solution for a broad range of health care functions where mobile and hands-free or limited-access systems are preferred or necessary and where the capabilities of other mobile devices are insufficient or inappropriate. For example, a web browser–like display, accessible through either a flatpanel, standard, or headset monitor, gives the beltpack TransPAC computer the functions of a complete desktop, including PCMCIA card interfaces for internet connectivity and a secure smartcard with 16-bit microprocessor and upwards of 64 M of memory (85).

Personal Image Transmission

Although not strictly in the biomonitoring theme of this review, we would be negligent not to present prospects for communicating a patient’s status through colored images of faces, wounds, rashes, or environmental situations requiring attention or advice from caregivers or rescuers. The general concept is shown in Figure 11. The current activities in the area of transmission of medical images involve experiments to determine the feasibility and weaknesses of transmitting ECG data or X-Ray CT image data through the Internet or through a commercial wireless network to a hand-held or pocket-sized display unit. High-bandwidth cellular phones being introduced to access the Internet [e.g., Nokia 7110 Mobile Application Protocol (WAP) phone] as well as currently available pocket computers have the capacity to receive two-dimensional images ranging from radiological images to images of people, places, or things (e.g., wounds, skin rashes) that can be acquired by miniature digital cameras.
Figure 11  Voice, personal image, whereabouts, and emergency data communication for the patient at risk can, in principle, be supplied by a miniature camera, LAN, and regional network.

Current experience is limited to only a few commercially available devices: pocket computers and personal data assistants (PDAs). Two currently available pocket computers are (a) the Hewlett Packard 620LX (Hewlett Packard, Palo Alto, California), which measures 19.5 by 10 by 3.2 cm and weighs 603 g, and (b) the Sharp Mobilon 4500 (Sharp, Mahwah, New Jersey), which measures 18.5 by 9.7 by 3 cm and weighs 483 g. Both have a 256-color, 640-by-240-pixel screen; run under the Microsoft Windows CE operating system; and come preloaded with a set of software that includes Microsoft Pocket Internet Explorer (Microsoft, Redmond, Washington), a World Wide Web browser.

Current experience with the transmission and reception of X-ray CT scans demonstrated the feasibility in a study with images from 21 patients but also showed the major limitation of 21 min when 14 images (40 kB each) were used on average for each case.

Connection initialization, transfer, and reception times are long because this experiment used only 9,600 kbps baud. We should expect rates of 57.6 baud, which, in principle, would reduce the reception of a single image from 90 s to 15 s.

Wireless connections between these pocket computers and the Internet through a telecommunications company’s CDPD network requires a modem, such as the Sierra Wireless Air Card 300 or 555 (Sierra Wireless Inc. Richmond, British Columbia, Canada; www.sierrawireless.com) as a CDPD modem. This credit card–sized device, with a 7-cm antenna that extends to 11 cm, can, in principle, operate at transmission speeds of 19,200 baud (model 300) or 152,000 baud (model 555).

Computers smaller than palmtops, known as PDAs, have recently developed screens of high enough quality to satisfactorily display a CT scan. PDAs are about two thirds the size of a palmtop computer, making the PDA more portable. Most PDA computers cannot yet accept any of the available wireless modem cards on the market. It is very likely that a wireless modem card for a PDA will soon be available.
or a new color PDA will become available that will accept existing wireless modem cards such as Sierra Wireless AirCard 300. An example of a PDA that can receive and display images is the Nokia 9000 (Nokia Ltd., Helsinki, Finland). The Nokia 9000 is a medium-sized hand-held device (17.3 × 6.4 × 3.8 cm) with a liquid crystal display of eight gray levels and 600 × 200 pixels and is a terminal device for image reception and viewing when combined with a GSM (Global System Mobile) digital phone with internet capabilities. Memory of 8 MB, with 2 MB for user data storage, can accommodate JPEG compressed radiologic optical images, which can be 40 kB. The acquired image data are nominally 256 × 256 or 512 × 512 (256 kB), and a reasonable JPEG quality factor is 75%. The field of patient and record image transmission is likely to be revolutionized with the development of miniature cameras or wrist-worn digital cameras, such as the Casio black and white 120 × 120 system illustrated in Figure 12.

**SUMMARY OF PRINCIPAL NEEDS AND PRINCIPAL LIMITATIONS OF WIRELESS MONITORING**

For the population at large, blood pressure and some measure of endothelial cell function or vascular relaxivity are two physiologic variables most would agree are sensitive risk factors for cardiovascular death from coronary occlusion or stroke. For acute and chronic care in the hospital and at home, blood pressure,
respiratory rate, ECG, and blood oxygen saturation are essential parameters that require more or less continuous monitoring. Although the radio spectrum restrictions continue to present some limitations, the FCC rules are changing to meet medical short-distance communication needs. A major limitation of power source continues to plague engineering design. Solutions, such as low duty cycle, the use of repeaters, or LAN networks made with higher power are practical. Wireless telemetry will make these measurements more efficient and more reliable and in some cases bring improved health care at a major reduction in cost.

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GLOSSARY

2G: Second generation of communication systems. Wireless communications systems using digital transmission and advanced control techniques to improve the performance of voice communications, provide special features, and limited digital messaging capabilities.

3G: Third generation of wireless communication systems. 3G is the newest generation of wireless communications systems, allowing greater bandwidth and opening the way to increased data-over-wireless solutions. The 3G mobile and services will transform wireless communications on-line, enabling real-time transfer of information, regardless of time and place. One will be able to send electronic postcards with images, and one can even have a live videoconference using a 3G mobile communication device.

3GPP: Third-Generation Partnership Project (W-CDMA). A global cooperative project in which standardization bodies in Europe, Japan, South Korea, and the United States, as founders, are coordinating W-CDMA issues.


AC: Alternating current or oscillating component of a signal in time.

ARDIS: ARDIS company, Lincolnshire, Illinois. A network that is exclusively designed for wireless data transmission, yet its maximum speed is still only 19,200 baud using its available wireless card modem.

BP: Blood pressure.

BSWD: Bell South Wireless Data. A company similar to ARDIS in that it is also exclusively designed for wireless data transmission.
CDMA: Code division multiple access. One of several digital wireless transmission methods in which signals are encoded using a specific pseudo-random sequence, or code, to define a communication channel. A receiver, knowing the code, can decode the received signal in the presence of other signals on the channel. This is one of several “spread spectrum” techniques, which allows multiple users to share the same radio frequency spectrum by assigning each active user a unique code. CDMA offers improved spectral efficiency over analog transmission in that it allows for greater frequency reuse. Other characteristics of CDMA systems reduce dropped calls, increase battery life, and offer more secure transmission.

CDPD: Cellular digital packet data. A method of wireless data communication transmitted over cellular telephone networks (see text).

CHIME: Collaborative Home Infant Monitoring Evaluation.

CT: Computer-assisted tomography, as in X-ray computed tomography.

D-AMPS: Digital Advance Mobile Phone Systems, based in the United States of America.

DC: Direct current or steady background signal.

DSTN: Double-layer super-twist nematic. A type of flat display screen that is generally used on laptop computers to display a passive matrix color screen. It uses two display layers to counteract the color shifting that occurs with conventional super-twist displays.

ECG: Electrocardiogram from which waveform and pulse rate are obtained.

EEG: Electroencephalogram from which various rhythms of electrical activity are detected from the brain.

ETSI: European Telecommunications Standards Institute.

FHSS: Frequency hopping spread spectrum.

FTP: File transfer protocol.

GPS: Global positioning system. The existing GPS radio wave bands are L1 at 1575.42 MHz and L2 at 1227.6 MHz.

GSM: Global systems for mobile telecommunications. Originally developed as a pan-European standard for digital mobile telephony, GSM has become the world’s most widely used mobile system. It is used on the 900-MHz and 1800-MHz frequencies in Europe, Asia, and Australia and on the MHz-1900 frequency in North America and Latin America.

GSM 900: GSM 900, or just GSM, is the world’s most widely used digital network and now operates in over 100 countries around the world, particularly in Europe and Asia Pacific.

Hb: Hemoglobin concentration.

HbO₂: Oxyhemoglobin concentration.

IEEE 802.11: Institute for Electrical and Electronic Engineers standard for 2.46-GHz short-range communication, such as that used for computers to computers and computers to modems for industrial access.

IMAP4: Internet messaging access protocol. A remote mailbox access protocol. It enables efficient operation, such as downloading only essential data, by first acquiring the email header prior to actual email download. This feature makes the protocol well suited to remote environments.
**Iridium:** Iridium world communications. Provides worldwide wireless communication coverage using a network of land-based and satellite-based communications. Iridium customers can be reached anywhere on the globe, but coverage is not reliable indoors in many areas.

**JPEG:** Joint photographic expert group. This is a means of compressing the size of computer images so they require less time to transmit and less storage space.

**LAN:** Local area network designates communication system that could be on the subject between a sensor and a CPU located on the belt; for example, with subsequent transmission from the CPU to another LAN or regional communication system, such as the cellular network.

**MRI:** Magnetic resonance imaging.

**PaCO₂:** Partial pressure of carbon dioxide in arterial blood.

**PCO₂:** Partial pressure of carbon dioxide in gas or air.

**PC:** Personal computer.

**PCMCIA:** Personal computer memory card international association. A computer connection standard for card-sized computer devices to attach to a portable computer by inserting it into a ‘PCMCIA’ slot.

**PDA:** Personal digital assistant. A very small pocket computer.

**PP:** Pulse (cardiovascular) pressure.

**PTT:** Pulse (cardiovascular) pressure transit time.

**RAN:** Radio access network. The ground-based infrastructure required for delivery of 3G wireless communications services, including high-speed mobile access to the Internet. The RAN must be able to manage a wide range of tasks for each 3G user, including access, roaming, transparent connection to the publicly switched telephone network and the Internet, and quality of service (QoS) management for data and Web connections.

**Repeater:** Receives radio signals from the base station. They are then amplified and retransmitted to areas where radio shadow occurs. Repeaters also work in the opposite direction, i.e., receiving radio signals from mobile telephones then amplifying and retransmitting them to the base station.

**RGB:** Red green blue. The three color dot elements that create all the colors on a computer or television screen.

**SaO₂:** Percent oxygen saturation in arterial blood.

**SAW:** Surface acoustic wave resonator or filter.

**SIM Card:** Subscriber identity module card. A small printed circuit board that must be inserted in any GSM-based mobile phone when signing on as a subscriber. It contains subscriber details, security information, and memory for a personal directory of numbers. A subscriber identity module is a card commonly used in a GSM phone. The card holds a microchip that stores information and encrypts voice and data transmissions, making it close to impossible to listen in on calls. The SIM card also stores data that identify the caller to the network service provider.

**Symbian:** Owned by Ericsson, Nokia, Motorola, Panasonic, and Psion, Symbian creates an advanced, open, standard operating system, Symbian OS, for its licensees. Symbian OS is designed for next-generation mobile phones and enables
a broad, international, developer community. Phones using Symbian OS include the Ericsson R380 and Nokia 9210.

**SWAP:** Shared wireless access protocol.

**TCP/IP:** Transmission control protocol/Internet. TCP/IP is the standard communications protocol required for computers communicating over the Internet. To communicate using TCP/IP, computers need a set of software instructions or components called a TCP/IP stack.

**TDMA:** Time division multiple access.

**UHF:** Ultra-high frequency. The RF spectrum between 300 MHz and 3 GHz.

**Uplink:** The transmission path from the mobile station up to the base station.

**UWB:** Ultra-wideband technology with a band from 3.1 to 10.6 GHz (see text).

**VHF:** Very high frequency. The RF spectrum between 30 MHz and 300 MHz.

**WLAN:** Wireless local area network. A wireless version of the LAN. Provides access to the LAN even when the user is not in the office.

**WML:** Wireless markup language. A markup language developed specifically for wireless applications. WML is based on XML.

**WWW:** World Wide Web. A system of internal servers that support specially formatted documents written in HTML (hyper text markup language) that permits display of text, graphics, audio, video, and so on, moving from one document or website to another by clicking on highlighted text (known as hyper text) or icons.

**XML:** Extensible markup language. XML is a format for structured documents and data. It was developed by the World Wide Web Consortium (W3C). It is a meta-language, i.e., content is not directly encoded in XML, but in a specific markup language defined using XML. It corresponds to the successor language for the current HTML. In contrast to HTML, where tags are predefined, the XML user can freely extend a data format applying his or her own uniquely defined tags.

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