Regular paper

Evolutionary paths in wireless communication systems

Wojciech Michalski

Abstract—The paper contains a review and analysis of evolutionary paths of seven most important, from network development strategy point of view, wireless communication systems, especially the WLAN operating according to the IEEE 802.11 standard. With respect to WLAN, trends related to evolution toward mobile network and self organizing network as well as toward integration of WLAN and GSM using GPRS are presented. Concerning WLAN architecture development, evolution paths toward distributed controlled network as well as centrally coordinated and controlled network are described. Moreover, analysis includes cellular mobile radio systems, wireless personal networks, wide area wireless packet data systems, satellite-based mobile systems, paging/messaging systems and cordless telephones. With respect to these systems, general evolution process and trends associated with this process are described.

Keywords—cellular mobile radio systems, wireless local-area networks, wireless personal networks, wide area wireless packet data systems, satellite-based mobile systems, paging/messaging systems, cordless telephones, access points, switches, GPRS, mobile IP, WLAN cellular integration.

1. Introduction

Wireless communications today is not a single technology, not a single system, and not a single service, but comprises many technologies, systems and services optimized for different applications. Wireless technologies are evolving as technology advances and in the evolution process some trends are becoming clear. The most significant of them are: mobility in communications and transformation from physical connections to communications networks. This article presents different trends observed in evolution of wireless communication systems, some factors stimulating this process as well as perspective and real chances of development of particular groups of wireless communications in the future.

2. Communications in wireless networks

Technologies and systems that are currently providing wireless communications services (or will provide them in near future) can be grouped into seven following groups:

- cellular mobile radio systems,
- wireless local-area networks,
- wireless personal networks,
- wide area wireless packet data systems,
- satellite-based mobile systems,
- paging/messaging systems,
- cordless telephones.

Systems mentioned above are treated as the most important from network development strategy point of view. The grouping is generally done with respect to degree of mobility and communications applications or modes. Particular groups and evolutionary trends concerning these groups will be presented below. Although evolution path is individual for each system, the purpose of evolution process is common – to be competitive and to satisfy needs of particular user groups.

Wireless communications may be considered from different points of view. The most important of them are user location and degree of mobility. User location can be determined as either indoors or outdoors as well as on an airplane, train or car. Degree of mobility can be defined by speed, e.g., vehicular, pedestrian, or stationary, as well as by size of area in which communications are provided. Mobility and portability may be implemented on following scales:

- within a house or building (cordless telephones, wireless personal networks, wireless local area networks),
- within a campus, a town, or a city (cellular mobile radio systems, wireless local area networks, wireless personal networks, wide area wireless packet data systems, paging/messaging systems, extended cordless telephones),
- in a region area (cellular mobile radio systems, wireless local area networks, wireless personal networks, wide area wireless packet data systems, satellite-based mobile systems, paging/messaging systems),
- country- or continent-wide (cellular mobile radio systems, wireless local area networks, wireless personal networks, paging/messaging systems),
- worldwide (cellular mobile radio systems, wireless local area networks, wireless personal networks, satellite-based mobile systems).

Systems working in both fixed and mobile networks can use two modes of communications: messaging and real time two way communications. The first one is for message transmission, storage and retrieval. It is used where

the communications is in not real time. This mode is typical for voice mail, fax and e-mail. The second one is represented by the telephone, cellular mobile radio telephone, interactive text and graphics exchange over data networks as well as video phone.
Wireless communications is based on different applications called agents. They are new high level software applications or entities being incorporated into some computer networks. When introduced into data network they are used to find information by some title or characteristic, and to return the information to the point from which the agent was initiated.

3. Cellular mobile radio systems

Cellular mobile radio systems may be defined as a solution providing high mobility (refers to vehicular speed), widespread coverage and wide ranging voice communications.
Cellular mobile radio systems have been evolving for many years. One evolutionary path was development from analog to digital technology. Systems working at 800 MHz have evolved to digital radio technologies operating in accordance with the following standards:

– global system for mobile communications (GSM) in Europe,

– time division multiple access (TDMA) digital cellular known as IS-54 and in the form of the code division multiple access (CDMA) digital cellular known as IS-95 in USA,

– Japanese or personal digital cellular (JDC or PDC) in Japan.

The most significant problem for digital cellular systems, considered in the design stage, is the cost of base stations. For this reason, process of digital system design is leaded toward maximizing users per MHz and per base station. Generally, regions between cities have a low population density, so a relatively high transmitter power to provide maximum range from high antenna locations is needed to cover highways running through such regions.
Digital cellular mobile radio systems have been evolving for over a decade and still evolve in different directions, e.g., toward solutions for small coverage areas or microcells. Thanks to these solutions, it is possible to increase the capacity in high user density areas and to improve coverage of shadowed areas. The microcells base stations installed inside (e.g., in conference center lobbies and similar places of high user concentrations) allow to reduce transmitter power. Microcells base stations are less expensive than conventional cell sites. Thus one can say that micro cell base stations increase system capacity and reduce cost per radio channel.
Another evolutionary path of digital cellular mobile radio systems is the development of GSM toward universal mobile telecommunication system (UMTS). There are two ways: directly according to third group partnership project (3GPP) or indirectly, with evolutionary path divided into following stages:

– GSM stage (solution providing 9600 bit/s data transmission in circuit-mode),

– general packet radio service (GPRS) stage (solution providing 160 kbit/s data transmission in packet-mode),

– enhanced data rates for GSM evolution (EDGE) stage treated as a type of GPRS (solution providing 384 kbit/s data transmission in packet-mode),

– GSM EDGE radio access network (GERAN) stage being second phase of EDGE (solution providing 1920 kbit/s data transmission in packet-mode),

– UMTS release R99 (phase 1) stage (solution providing 2 Mbit/s data transmission in packet-mode),

– UMTS release R4 and R5 stage (related to successive phases of UMTS development).

Till now, only GSM and GPRS technologies have a practical meaning. Although cellular mobile data systems have existed for over 10 years, but only recently their speeds become faster due to introduction of GPRS on GSM.

4. Wireless local-area networks

Wireless local-area networks (WLANs) may be a solution providing network connectivity in areas difficult or impossible to wire and allowing mobile applications to work with traditional wired local-area network (LAN) applications. They provide simultaneous mobility and connectivity as well as high flexibility for moves, adds and changes. They do not replace wired solutions, but only complement them. They are treated as a LAN solution for true mobile devices. This technology has been in contention whether it is a competitor or a complement to 3G. Now, it is generally accepted to be a complement.
Wireless LANs is a technology that provides access to mobile Internet as opposed to Internet over a cable. Internet access may be achieved through asymmetrical digital subscriber line (ADSL), cable television (CATV) combined with WLANs at home or in office, and hot spots belonging to WLANs, GPRS or UMTS. Wireless LANs give coverage everywhere and high speed coverage in hot spot areas. They provide roaming between hot spots and mobile areas. This technology may be used mainly (but not only) by mobile operators because they have access to mass market and technologies to mitigate problems arising from billing and roaming.
Wireless LANs have existed for many years, but only recently, when 802.11a standard [7] solution was built, they are treated as feasible high speed wireless solution. With speeds up to 54 Mbit/s and cheap access points (APs),

WLANs can provide communication anywhere, anytime and with expanded range of services, using several APs. In many countries of the word, fixed and mobile network operators as well as Internet service providers have deployed APs in places such as hotels, airports, coffee shops, etc. These areas known as hot spots are the places where people are concentrated and like to use wireless services.

Wireless LANs are evolving in several directions. The first one is evolution from corporate to public networks (based on hot spots). The second one is toward extending mobility (wireless communication anytime and anywhere provided by "mobile" hot spots). The last one is toward self-organizing (*ad hoc* networking).

Another evolutionary paths of WLAN are integration of WLAN and GSM/UMTS and development of WLAN architecture toward distributed controlled network (intelligent peripheral devices) as well as toward centrally coordinated and controlled network (intelligent central nodes).

4.1. Development of WLAN toward extending mobility

According to the needs of users, WLANs as well as Internet protocol (IP)-based networks are evolving toward mobile networks. The most important thing in this process was implementation of appropriate protocols, thanks to which there are micro- and macro-mobility in WLANs. Micro-mobility exists when mobile node (MN) moves between different base stations (BSs) within the same region. Macro-mobility appears when MN goes to BS to the other region. Micro-mobility may be supported by, e.g., cellular IP (CIP) protocol which provides host-based routing schemes as well as hierarchical tunneling schemes. Macro-mobility is based on mobile IP (MIP) protocol, which can provide means to roam among networks without changing IP address. Generally, one can say that MIP and CIP play a key role in integration of different link layer technologies with the promise of enabling transparent mobility through use of a unified network layer.

Extended mobility in WLANs is supported mainly by roaming and handoff mechanisms. Thanks to roaming, it is possible to move between different networks (WLANs, GSM) and different operators. When mobile nodes roam among networks, they are handled by two agents: home and foreign agent. Home agent (HA), located in the home network, provides central mapping of home address to care-of address. Foreign agent (FA) provides possibilities for tunneling endpoint in case when MN is using foreign agent care-of address. Both home address and care-of address are associated with MN at all times when MN is away from the home network and they support the routing procedures. The first one is an address of the MN on its home network. The second one is temporary address on a foreign network. Handoff provides means needed to move from one area to another without interruption of active session. Handoff procedure may be performed by hardware and software in three steps. In the first one, an active MN sends a route update packet when it moves to the new BS. In the second one, when the MN changes to the new, BS packets from the old BS are lost (by hardware). In the last one, packets from both BS are received during overlapping (by software).

4.2. Development of WLAN toward self-organizing network

Wireless LANs as well as wireless personal networks distinguish *ad hoc* nature of their compositions (e.g., interconnecting structures and local foreign as well as remote personal and foreign devices). Moreover, their compositions characterize the heterogeneity of technologies, applications and devices. Access to infrastructure may not always be available or may be incidental (*ad hoc*). On the other hand, they have rapidly changing parameters, e.g., caused by terminal mobility and link failures. For these reasons, as typical mobile *ad hoc* networks, WLANs are currently developing toward improvement of *ad hoc* networking solution. In this solution, currently some concepts concerning resources recognition (which resources are around and available either locally or remotely), techniques for resources recognition (proactive and reactive strategies, advertising, soliciting, etc.), architecture for resource recognition, context recognition (which units constitutes the context for WLAN and its parts) as well as security and privacy are being deployed.

It is very important, that in self organizing network, based on *ad hoc* networking solution, every terminal has the same function, and network is formed dynamically (*ad hoc*) by communications exchange among terminals.

4.3. Integration of WLAN and GSM

This direction of WLAN evolution results mainly from need to broadband access services by some group of mobile subscribers. Development of UMTS is limited by necessity to build access networks (almost always from the beginning) and low interest in the UMTS services by large group of potential users. In this situation WLAN associated with GPRS is treated as a good solution for mobile networks.

There are three methods of integrating WLAN and mobile networks using GPRS:

- tight coupling,
- loose coupling,
- open coupling.

Tight coupling is the case when WLAN is directly connected to GPRS/GSM core network. It means integration on a radio level. Controllers can handle both base stations of WLAN as well as base stations belonging to GPRS/GSM. In this model all traffic generated in WLAN goes through the GPRS/GSM core network. It gives the service provider the ability to exclusively own and operate the WLAN network. The benefit of this solution is using (by WLAN) the cellular data core infrastructure, authentication and billing

systems as well as providing access to core service such as short message service (SMS) and multimedia messaging service (MMS).
In case of loose coupling, WLAN is treated as an access network complementary to the cellular network. It means that WLAN is not directly connected to GPRS/GSM core network but it only adopts some mechanisms used in GSM network, especially authentication and billing functions. In this case, networks are integrated on the link layer (it concerns link connecting authorization, authentication, accounting (AAA) server (located in WLAN) and home location register (HLR) (located in GSM)). This solution enables easy roaming between different WLANs and cellular networks, which is important requirement as many service providers exist.
In case of open coupling, interworking WLAN and GPRS/GSM is on billing level only. This solution has problems, eg., concerning authentication that are overcome by providing WLAN direct access to external networks and having common location for this.
The best solution is tight coupling, because it provides common mechanisms concerning security and handover procedure in both networks. But it requires many changes in access network infrastructure. Open coupling is the simplest solution, but it does not give possibilities offered by tight coupling. The optimum solution is loose coupling, because it ensures low cost and provides modern network with GSM security mechanisms, especially authorization and authentication procedures used in GSM network.

4.4. WLAN architecture development toward distributed controlled network

Wireless LANs development toward distributed controlled network means developing intelligence of peripheral devices. This evolutionary path is related to increasing WLAN functionality in access points exclusively. This concept is preferred to develop the most typical WLANs based on the hot spots acting independently.
Architecture of the networks based on intelligent peripheral devices consists of segment of WLAN radio access, switch and router. Segment of WLAN radio access is composed of access points working in accordance to a given standard, e.g., IEEE 802.11b [7]. In this segment the mechanisms concerning access control and billing are implemented. APs are connected with router by switch. The role of access points is connecting WLAN to structured wired networks and transmitting data between wired and wireless networks. APs provide access to others networks, but don't participate in internal connections (peer-to-peer). Users may roam between APs without interrupting active connections (same as in cellular networks). The main role of router is handling dynamic host configuration protocol (DHCP) as well as WAN connecting hot spots and backbone network. Backbone network as a main segment of WLAN concentrates traffic generating in particular hot spots.
Wireless LANs based on intelligent access points have decentralized control functions. They may support wide scope of functions and services implemented in their software. Due to large number of APs, installation costs are higher than in case of intelligent switch solution, especially related to multisystem devices working in both IEEE 802.11a and b standards.

4.5. WLAN architecture development toward centrally coordinated and controlled network

This direction of WLAN development is related to deploying software functions of the switch treated as main control device. It concerns all the functions including control, network management, handling of protocol layers (layer 2, 3, 4), filtering and data packets management as well as functions concerning security and privacy in WLAN. Thanks to filtering, administrator may assign priority to delay-sensitive packets. It concerns especially packets carrying voice data related to voice over WLAN (VoWLAN) (the service being a new application of WLAN). Moreover, in accordance with this idea, the switch is responsible for handling quality of service (QoS) functions, load balancing and access to telecommunication services. Some intelligent switches can handle simple as well as intelligent APs.
Intelligent switch has implemented typical application used to transferring packets between wired and wireless networks as well as traffic observation and measurement functions. Moreover, VoWLAN is possible thanks to implementation of QoS mechanisms. In this solution access points perform functions of network adapters only. They are used for simple transfer of data packets through radio link to the subscriber mobile nodes. They haven't any control and management functions or authentication and encryption mechanisms, because all these functions are implemented also in the switch. Switch acts in centralized mode and performs supervision functions too (in particular functions concerning reconfiguration of APs). Thanks to concentration of all the main functions at central point of the network, access points may be simple and cheap. For this reason, network construction and maintenance costs may be lower.
Solution based on intelligent central nodes is related to large WLAN, composed of large number of APs. It is dedicated to operators having hot spots in such locations as airports, hospitals, schools or large shopping centres. Due to location of all functionality in one place, two switches are required for security, especially for WLAN which must work without interruptions (in hospitals and critical public places). This model enables easy creation and upgrade of wireless networks.

5. Wireless personal networks

Wireless personal networks may be defined as systems working in the intelligent spaces, using radio signal for transferring information exchanged between different elec-

tronic devices. These networks make possible enhancement of our personal living environment and work by dynamically networking computers, PDAs, phones, headsets, viewers, appliances, sensors and actuators. They are confined to the vicinity of the person, or personal operating space and have generally an *ad hoc* character.

Wireless personal networks are centered around a person and his/her needs. Resources and partners are not necessarily in the close vicinity of the person. These networks are distinguished by their dynamics. First, dynamics of personal networks results from large variety of heterogeneous nodes connected in an *ad hoc* network and in a dynamic fashion. Second, state of the nodes may change from active to stand by and disconnected during the operation of the network. Moreover, network topology, hierarchy and constituent nodes may change continuously and access to the infrastructure network may not always be available or may be incidental (*ad hoc*). Dynamics of composition, configuration and connectivity depends on time and place. Core consisting of a PAN may be extended on demand with personal resources or resources belonging to others.

Wireless personal networks may handle internal calls as well as incoming and outgoing calls (from/to fixed, mobile, IP and others personal networks). External calls initiated by mobile phones are routed through GSM interface, calls initiated by information devices are routed through Bluetooth interface. Bluetooth is a new technology developed by consortium of Ericsson, Intel, IBM, Nokia, Toshiba and others, providing connection of peripheral devices, bridging of networks and supporting of *ad hoc* networking (e.g., GPRS via mobile phone – Bluetooth – laptop).

Wireless personal networks, especially based on Bluetooth technology, are treated as scatternets. They are built in piconets topology. Each piconet has one master and up to 7 slaves. Master determines hopping sequence and slaves have to synchronize. Participation in piconet means synchronization to hopping sequence. Communication between piconets means that devices jump back and forth between the piconets. Unit located in all piconets is the main point connecting two or more piconets. Each Bluetooth device may work as slave in multiple piconets and as master in one piconet only. Thus, the following types of Bluetooth devices may operate in scatternets:

- unit treated as a master,
- unit treated as a slave,
- unit treated as a master in one and as a slave in another piconet,
- unit treated as a slave in two or more piconets,
- unit treated as a master in one and as a slave in two or more piconets.

Wireless personal networks also have been evolving in several different directions. First, they have changed from systems using IrDA and UWB technologies to Bluetooth and IEEE.802.15 standards. Second, they have evolved from personal networks based on private branch exchange (PBX) and Centrex applications to the edge networks providing different applications, e.g., telepresence sessions, walking through a smart building, health monitoring and business environment extended to the car. Examples of edge networks are:

- personal area networks (PAN),
- body area networks (BAN),
- personal networks (PN),
- smart environments,
- sensor networks,
- home networks,
- vehicle networks,
- inter-vehicle networks.

Another evolutionary path is the *ad hoc* networking. It is optimized for use in personal environments, because WLANs have typically *ad hoc* nature. For this reason, security and privacy are very important for these networks. In more cases, current wireless infrastructure based on self-organization cannot furnish the necessary bandwidth and protocols to provide services to users traveling at highway speeds, although there are several security and handoff protocols providing required protecting mechanisms and QoS.

Mobile personal networks based on GSM, UMTS as well as public WLANs are built. Fixed personal networks are built using private WLANs and Bluetooth technology. Mobile users and vehicles may use multimode terminals working in GSM and UMTS networks and WLANs. Currently, some operators offer different applications for wireless personal communication dedicated fixed, mobile and wireless communication in vehicles (virtual home or virtual office in vehicles).

6. Wide area wireless packet data systems

Wide area wireless packet data systems may be described as a solution providing high mobility, wide ranging, low rate digital data communications to both vehicles and pedestrians. These systems have been deployed for several years and have established a customer base in many countries. They haven't experienced such a spectacular, rapid growth like voice technologies although they have existed for a long time.

Wide area wireless packet data systems have been evolving in different directions, especially toward improving base station capacity, reducing total cost, and improving scope and attractiveness of services. Finally, the cellular digital packet data (CDPD) was developed, serving as overlay to cellular radio network. CDPD shares 30 kHz spaced 800 MHz voice channels; CDPD base stations share cell sites with a voice cellular radio system.

Thanks to this, the new wide area packet data network allows to reduce the cost of packet data service and to provide 19.2 kbit/s data rate.
Another evolutionary path leads toward smaller coverage areas as well as microcells. By using very small and inexpensive base stations the service costs may be reduced. Small base stations may be located inside buildings, and may be widely distributed throughout a region. To reduce cost of the interconnecting data network, sometimes the base station to base station wireless links are used. But if the same radio channels are seized that are used to provide service, the overall capacity to serve users is reduced. Capacity may be increased by adding base stations connected to fixed distribution network. It may be increased also by using other dedicated radio channels to interconnect base stations. Generally, the microcell data networks are dedicated to stationary and low speed mobile users.

7. Satellite-based mobile systems

Satellite-based systems may be defined as solution providing two- or one-way limited quality voice transmission, and/or very limited messaging and data transmission, to very wide ranging vehicles and fixed locations. They provide both large mobility and very wide coverage better than very expensive base station systems. The best known system is Motorola's Iridium, but there are also other satellite-based systems like Globalstar, Odyssey and Teledesic.
The purpose of satellite-based systems is to provide large area (often global) coverage to users. Providing the small coverage cells (e.g., inside buildings as well as in locations shadowed by buildings, trees and mountains) from earth orbit is very difficult. Moreover, the wide overall coverage, low capacity and high cost of orbital base stations makes telecommunication services offered by these systems very expensive. For this reason, satellite systems cannot compete with terrestial systems operating in populated areas. They may be treated as complement of terrestial cellular systems dedicated to low population density areas only.
Satellite-based systems include low earth orbit systems (LEOS), intermediate or medium height systems (MEOS) and geostationary or geosynchronous orbit systems (GEOS). LEOS is a system having tens to hundreds of satellites. It consists of more, but less expensive, satellites covering the earth. LEOS satellites can more easily cover smaller coverage areas and provide higher capacity within a given bandwidth. Moreover, transmission delay in LEOS is significantly smaller and quality of voice transmission is significantly better than in other systems. GEOS consists of few satellites only (perhaps only three). The satellites are more expensive. GEOS provide lower capacity within a given bandwidth and transmission delay is significant (about 0.5 s). MEOS is located between LEOS and GEOS in both technical as well as economic aspects.
One can say, there are not and there will (in the near future) not enough users in low population density regions of the world, having enough money, to make satellite-based systems economically viable. Possible development of satellite systems is limited to being a complement to GSM system only.

8. Paging/messaging systems

Paging generally may be defined as one-way message delivering solution operating over wide area. One-way radio link is adopted to the asymmetry of transmission. This system is distinguished by high antennas and high power transmitter located at the fixed base station as well as very low power consumption pocket paging receivers. Thanks to this, it provides long usage time from small batteries. Paging was deployed and has experienced rapid growth for many years. This technology began many years ago as a one bit messaging system. The one bit can only inform that someone wants to communicate with called subscriber.
Paging has evolved in several directions. First, it has changed from analog tone coding technology enabling user identification to digitally encoded messages technology. Second, it has evolved from one bit messages to multi-bit messages. In this evolutionary path it has evolved from one bit information meaning "someone wants to communicate", through the calling party's telephone number to short e-mail text messages, offered at the end of evolution process.
Another evolutionary path was two way paging. However, in practice this concept was unrealizable, because two-way communication disturbs the asymmetrical transmission associated with paging. Moreover, two-way paging technology requires a transmitter in the user set, and involves all the problems of two-way radio system that must be developed. For this reason, one can say that two way-paging is not an appropriate solution for this purpose.

9. Cordless telephones

Cordless telephones may be described as a technology providing voice communications with low mobility with reference to the range and user speed.
First cordless telephones based on analog radio technologies were introduced in late 1970s. In this period they experienced the greatest growth. Analog cordless telephones have evolved toward digital radio technologies in different forms. One of them was 2nd generation cordless telephone (CT-2) technology. The second one was digital European cordless telephone (DECT) technology and several different solutions of industrial scientific medical (ISM) band technologies developed in the USA.
In Europe, CT-2 technologies have been evolving for few years in the direction of extending their domain of use besides residences. This evolutionary path comprises development of CT-2 toward telepoint solution as well as phone point service. CT-2 phone point service has grown rapidly mainly in Asian countries (e.g., Singapore and Hong Kong).

Among European countries it was implemented in UK, but it was introduced twice before it became attractive enough for customers. Customers of CT-2 using handsets registered with the point provider can initiate and receive calls in area handled by their telepoint. However, they can not use their handsets if they move besides area to which the call was initiated, because CT-2 technology does not support transferring active wireless calls from one phone point to another. Limited range of capabilities of handoff is provided by CT-2+ technology, which is being deployed in Canada. As in case of other wireless communications, CT-2 base stations were located in places of big concentration of people (along city streets, in the shopping malls, train stations, etc.).

Another evolutionary path of European cordless telephones is DECT. This technology provides handoff capabilities when users move between different base stations. DECT base stations are handled by controllers connected to public exchanges or private branch exchanges.

Originally, the fundamental task of cordless telephones was providing economical voice communications inside residences. For this purpose, the wire located between telephone base unit and its handset was replaced by a short wireless link. The benefits obtained by developing this technology include minimizing total cost and maximizing the talk time.

10. Conclusion

Wireless communication systems presented in this paper include seven groups of technologies and systems providing voice and data services and having different degrees of mobility. All of them are evolving to better meet the demands of various groups of users. Different trends and several different development paths may be observed in development of wireless communications. The highest growth distinguishes three groups of technologies: cellular mobile radio systems, wireless local area networks and wireless personal networks. It is not yet clear in which direction the remaining groups (i.e., wide area wireless packet data systems, satellite-based mobile system, paging, and cordless telephones) will go, and whether they will be completely merged with one of above mentioned groups. It is quite clear that part of them will be included in functionality of 3rd generation networks. One can say that cellular mobile radio systems will evolve toward packets data systems based on IP technologies, WLANs toward high speed technologies and wireless personal network toward edge networks operating in intelligent spaces. WLANs will be integrated with existing GSM cellular networks, although integration of these networks is not as simple as it may seem. Many issues exist for which solutions are required or must be improved, e.g., session continuity, inter-carrier roaming, developing a dual band devices (WLAN and cellular system) as well as authentication and billing.

References

[1] C. Blondia, "Mobility support in IP-based network", 2003, www.telecom.ece.ntua.gr/nexway/

[2] A. R. Prasad, "Technological and economical challenges of public WLAN", www.telecom.ece.ntua.gr/nexway/

[3] I. G. Niemegeers, "Ad hoc distributed personal networking", in *Worksh. Broadband Wirel. Netw. Technol.*, Aveiro, Portugal, 2003.

[4] T. Van Leeuven *et al*., "Broadband wireless communication in vehicles", in *Worksh. Broadband Wirel. Netw. Technol.*, Aveiro, Portugal, 2003.

[5] "Next-generation networks", IEEE Web ProForum, www.ieee802.org

[6] "Networks", www.wobopedia.com

[7] "IEEE Standard for Information Technology – LAN/MAN – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", ISO/IEC 8802-11, 1999.

Wojciech Michalski was born in Bogate, in Poland, in 1952. He received the M.Sc. degree in telecommunications engineering from Warsaw Technical University in 1977. He has been with the Switching Systems Department of National Institute of Telecommunications (NIT) since 1977, currently as a senior specialist. His research interests and work are related to PSTN backbone and access networks, GSM networks and IP networks. He is an author and co-author of technical requirements and many documents concerning telecommunication services, FSK protocol, charging and accounting and network maintenance.

e-mail: W.Michalski@itl.waw.pl

National Institute of Telecommunications

Szachowa st 1

04-894 Warsaw, Poland