Next-generation wireless communications concepts and technologies

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Robert Berezdivin
Catapult Technology

Next-Generation Wireless Communications Concepts and Technologies

Robert Berezdivin, Robert Breinig, and Randy Topp, Raytheon

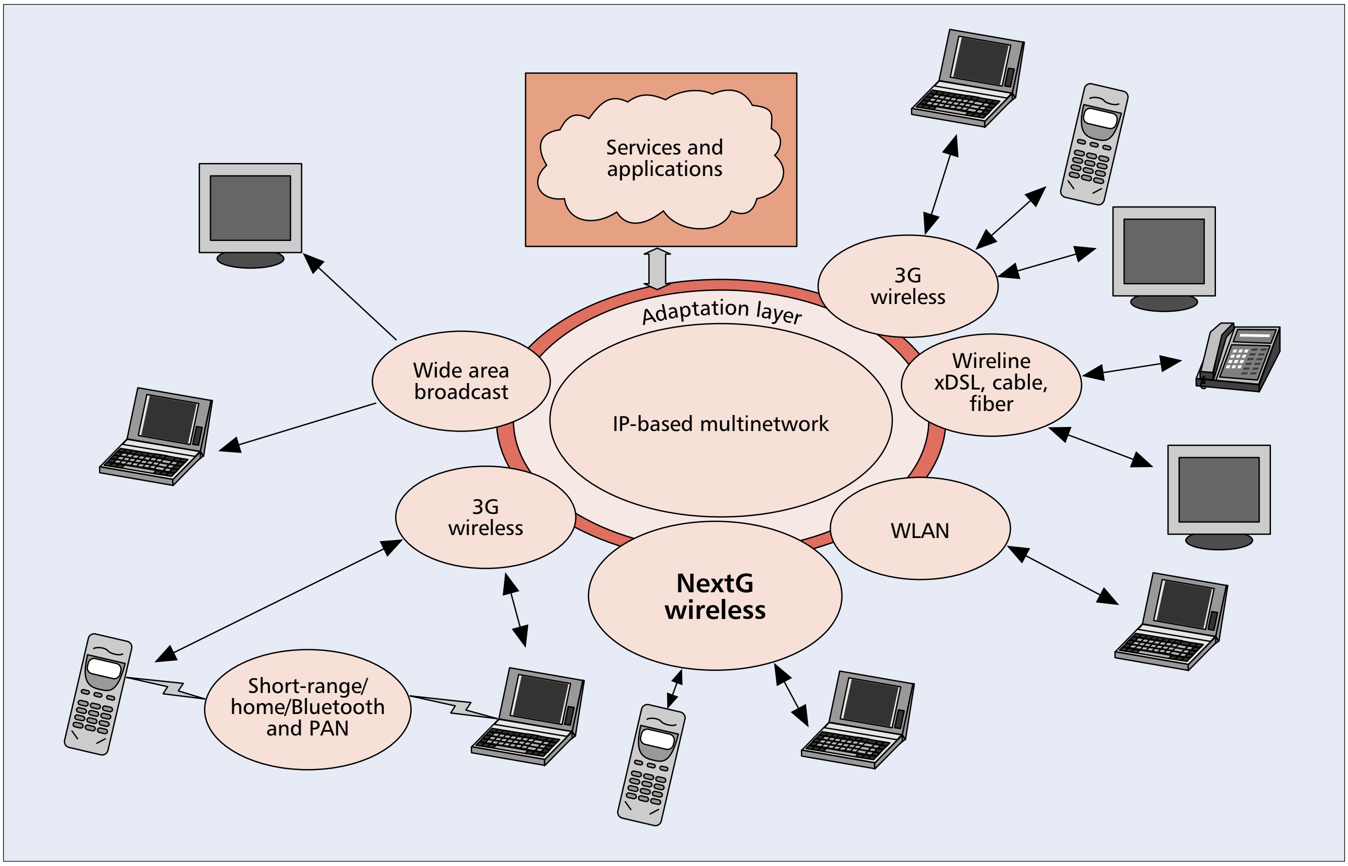
ABSTRACT

Next-generation wireless (NextG) involves the concept that the next generation of wireless communications will be a major move toward ubiquitous wireless communications systems and seamless high-quality wireless services. This article presents the concepts and technologies involved, including possible innovations in architectures, spectrum allocation, and utilization, in radio communications, networks, and services and applications. These include dynamic and adaptive systems and technologies that provide a new paradigm for spectrum assignment and management, smart resource management, dynamic and fast adaptive multilayer approaches, smart radio, and adaptive networking. Technologies involving adaptive and highly efficient modulation, coding, multiple access, media access, network organization, and networking that can provide ultraconnectivity at high data rates with effective QoS for Next Gare are also described.

INTRODUCTION

Mobile wireless technologies beyond the third generation (3G) are being investigated and discussed in industry and universities, in government and international organizations, and in professional conferences, journals, and fora. These reflect a view of wireless that continues to evolve, but which is also at the beginning of a significant change in wireless systems and services. One view, expressed in many ways and formulated in the IST-initiated, now independent, Wireless World Research Forum in their Visions of the Wireless World [1], is that of a paradigm shift. The shift is seen as driven by both a growing worldwide market for higher-quality higher-speed wireless services, and a technological tour de force leading wireless into a form of technological revolution that combines the ubiquitous nature of both the Internet and the PC. We label this *next-generation wireless* (NextG). We encompass "Beyond 3G" as the International Telecommunication Union (ITU) describes it in some of its position papers in working groups, "Beyond 3G" and 4G as treated and discussed in IEEE and WWRF publications and fora, as well as recent activities in enhancing wireless LAN and MAN (WLAN, WMAN), and in efforts toward a much more useful wireless Internet. We do not limit it to these since we believe that there can be other innovative approaches to the next generation of wireless communications arising from other sources. In this article we explore and describe some of the concepts and technologies we believe will form a part of this continuing burst of innovation. It is clear that there will be some technologies, or highly efficient implementations of them, that will remain behind closed doors for some time as players protect their intellectual property, even while national and international standards for these or similar technologies get developed.

NextG includes concepts and technologies for innovations in architectures, spectrum allocation, and utilization, in radio communications, networks, and services and applications. These major areas are intertwined, and innovations in one will inevitably lead to changes in the others. There have already been publications that review some technical areas and possible paths for the next generation of wireless systems and technologies [2–5]. The WWRF [1] is an ongoing forum on the markets, technologies, and applications and services. Our intention is to provide neither a comprehensive review of those nor of the technology, but instead to present and highlight some concepts and technologies we believe will be critical drivers in this possible paradigm shift. This article should not be taken as a status review nor a prediction of what will happen in wireless, but as presenting one view of what may happen in efforts toward a next-generation wireless world. We will cover some concepts of where



■ **Figure 1.** *Multiple access approaches and networks in a multinetwork.*

and how NextG may go in providing ubiquitous services, the architectural issues involved, and describe approaches to dynamic spectrum assignment (*smart spectrum*) and adaptive resources (*smart resources*). New concepts and technologies in each case will be discussed. Both radio and network topics are covered.

This article thus covers:

Ubiquitous services and paradigm change
- Ultraconnectivity
- Flexible networks

Smart spectrum and dynamic spectrum assignment

Smart resources
- Adaptive resource management
- Dynamic layers and fast adaptation
- Software radios and smart radios
- Advanced adaptive waveforms (modulation and coding) and physical layer
- Quality of service (QoS), adaptive networks, and universal access nodes

Ubiquitous Services and Paradigm Change

Ubiquitous communications involves a desire that continues to drive people's expectations of wireless technologies. Current second-generation (2G) and emerging 2.5G and third-generation (3G) [6] systems are providing a glimpse of the possibilities. Relatively cheap and effective voice services have shown, in 2G, that mobile wireless can indeed provide the desired QoS — basically availability, voice quality, and few dropouts — to users. 2.5G and 3G are being introduced with a useful capability for data and higher-speed services, and including some video services. WLAN and WMAN technologies are becoming more prevalent, although a convergence with wide-area networking is still in its infancy. And although these approaches and their extensions are striving toward an all-IP network, a multitude of technological and architectural factors, as well as business and political issues, are such that high QoS and truly ubiquitous voice and high-speed services will still require a major change as envisioned for NextG. An architecture more like that in Fig. 1, similar to that published by the WWRF [1], where multiple networks are able to function in such a way that the interfaces are transparent to users and services, and with a multiplicity of access and service options, is a key part of the paradigm change. Much as the Internet freed users from their own local networks and worrying about the interfaces to get to other networks — indeed, making it ideally transparent — wireless-inclusive multinetworks will need to provide that capability to wireless users.

New capabilities are needed to provide ubiquitous services. One is clearly the technology for the functional integration of the multinetwork. Since it will be based on the IP set of protocols (there is currently no foreseeable alternative; IP is the best integration technology), there is a need to adapt the networks and technologies to it. Furthermore, in order to provide high QoS in broadband wireless there is a need to develop, for NextG, a wire-

The demand for more spectrum will not abate and NextG will be no exception. But a much more efficient use of the spectrum across many bands and technologies is also possible. Spectrum that is not being used efficiently, at any frequency, geographical area, and time, is wasted.

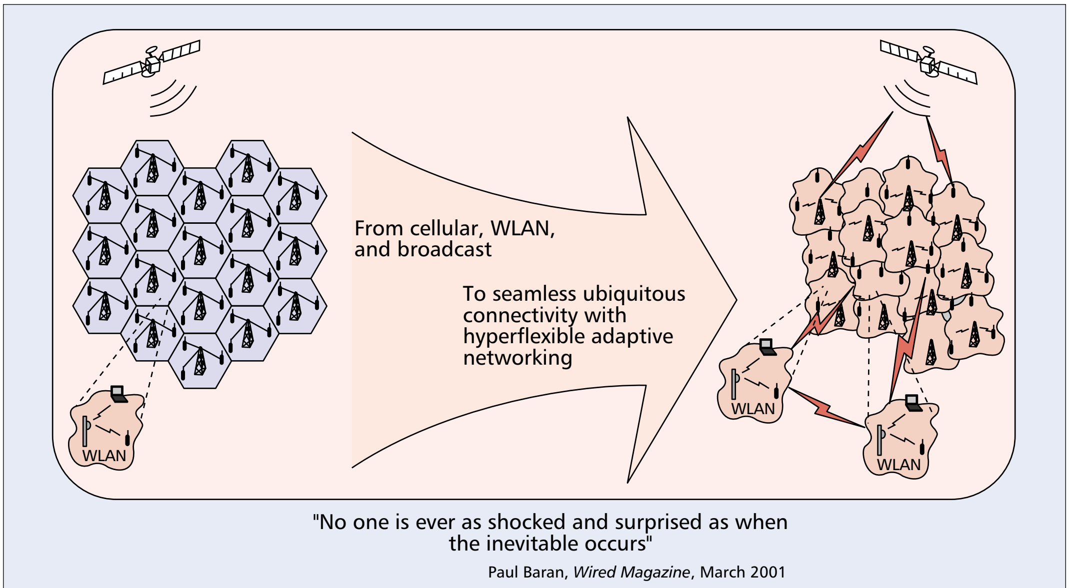


Figure 2. *Ultraconnectivity enables users to connect and communicate seamlessly.*

less technology that is not only IP end to end (still implying a possible non-IP segment), but one that best uses the IP packet switching concepts and technologies over the air, a native wireless IP mode. Over-the-air packet switching can replace the 2G/2.5G/3G basic circuit switching technologies, not only in the core network, but also in the air interface. 3G is already partially there with packet modes within physical channels for latency-insensitive data, but the use of packet channels for even low-latency voice and video can be expanded. Assigning packets to virtual channels and then multiple physical channels would be possible when the access options are expanded, permitting better statistical multiplexing and QoS management. In NextG the availability of pools of bandwidth (and capacity) that are adaptively assigned to service providers or into a shared pool, and then to user channels, can make the packet switching paradigm effective. More than likely some level of virtual circuit or virtual channel reservation scheme will be necessary for low-latency services, but the assignment can be done much more dynamically, and thus more effectively provide QoS while optimizing bandwidth and capacity resources. The key need here is for an IP-centric multinetwork, with *true IP* wireless capability having much greater adaptability to the resources available and to the traffic and service needs. The basic integration of core networks into an IP-based multi-network is already a goal in the Wireless Internet and in 2.5G/3G and their extensions. We will cover below the needs and technologies for *true IP* and the *adaptability* needed to make wireless part of an effective multinetwork.

A related principle of ubiquitous services is universal technical access: not the social issue of providing access for everyone, although that is a worthy social, economic and political goal, but the technical means by which this is done. We label this *ultraconnectivity*. Enough inexpensive access points in enough places, with devices that can seamlessly access those points at the desired data rates and QoS, are required. Figure 2 indicates one view of a flexible multinetwork with multiple access options providing users the capability to connect and communicate easily and seamlessly. Nodes and devices that can implement various categories of access technologies and networks, and the access technology and networks that can facilitate this, are the needed capabilities.

Ultraconnectivity is enabled by:

- Wireless networks seamlessly operating with other wireless networks, and with wireline networks and the Internet
- *Seamlessness*, which can lead to multiple requirements at various levels, but implies a melting away of access and interface barriers between networks and between service providers, and the emergence of a wireless true IP over-the-air technology
- Highly efficient use of the wireless spectrum and resources
- Flexible and adaptive systems and networks
- Distributed intelligence and wireless resources

NextG will spur the breaking of the wireless barriers, across both service providers and technologies. Figure 3 depicts some of the wireless network technologies, their evolution, and their position toward a next-generation wireless system that provides seamless services across them.

Smart Spectrum and Dynamic Spectrum Assignment

The demand for more spectrum will not abate, and NextG will be no exception; but much more efficient use of the spectrum across many bands and technologies is also possible. Spectrum that is not being used efficiently, at any frequency, geographical area, and time, is wasted. Dynamic spectrum allocation, assignment, and utilization is beginning to be seriously considered, as a way to both achieve higher total spectral efficiencies and provide better QoS while functioning under spectral and capacity restrictions as the traffic loads

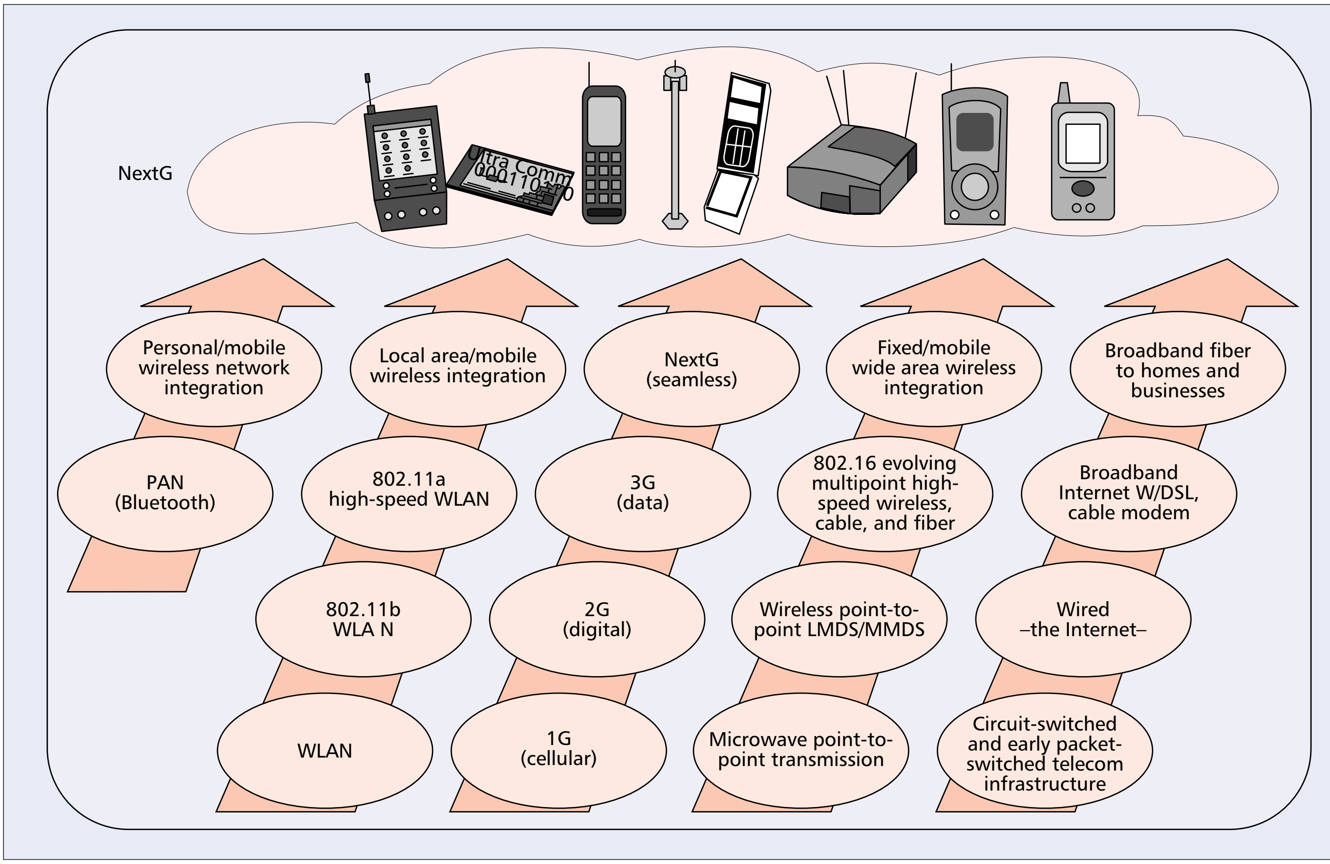


Figure 3. *Breaking the barriers across various wireless access and network technologies.*

change over a multinetwork. The concept of having a spectral resource allocated, assigned, or used in ways other than statically are under investigation in the United States, Europe, and Asia, and along with spectrum sharing is beginning to be considered as a possibility by government, industry, and market analysts [1, 7]. A view of spectrum as a critical wireless resource, and the access and control techniques that would permit it to be dynamically controlled being within reach, pervades the technology rationale for it. Advances in understanding spectral needs and usage, along with physical, MAC/link, and network layer approaches to optimize the use of spectrum, and also including the processing resources to control them, are needed to provide the right level of services and QoS. Regulatory and system changes would clearly be necessary, and effective economic inducements to it will in the end determine whether the service providers and the marketplace accept this concept. Figure 4 shows a simple conceptual case where dynamic spectrum assignment is used, and bandwidths and capacities are assigned and used based on dynamically varying traffic loads, QoS needs, market pricing, and other factors. The percentage of spectrum service providers draw from a common pool can be negotiated and determined by variable economic and service conditions.

The technical means to dynamically assign or utilize spectrum involves:

- Highly adaptive modulation and coding techniques
- Multidimensional/hybrid multiple access techniques
- A spectrum- and resource-aware MAC/link layer
- Flexible networking
- Spectrum awareness and multilayer resource management

Smart Resources: A Technological Vision

From a technological reference point there are four major factors in achieving the degree of integration, flexibility and efficiency envisioned

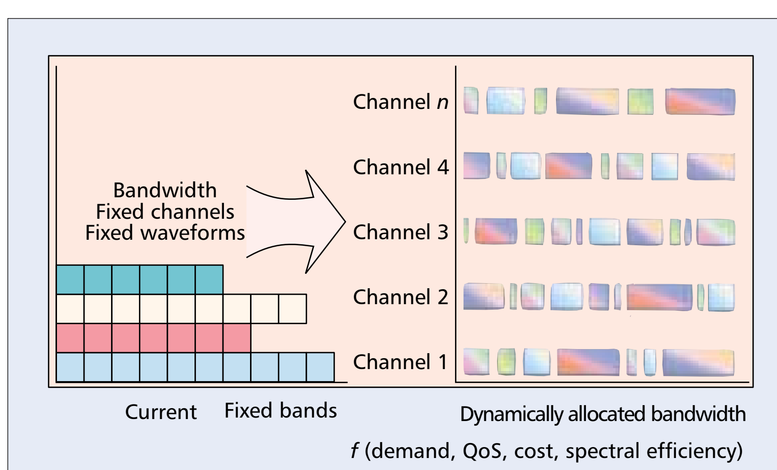


Figure 4. *Dynamically assigned and used spectrum.*

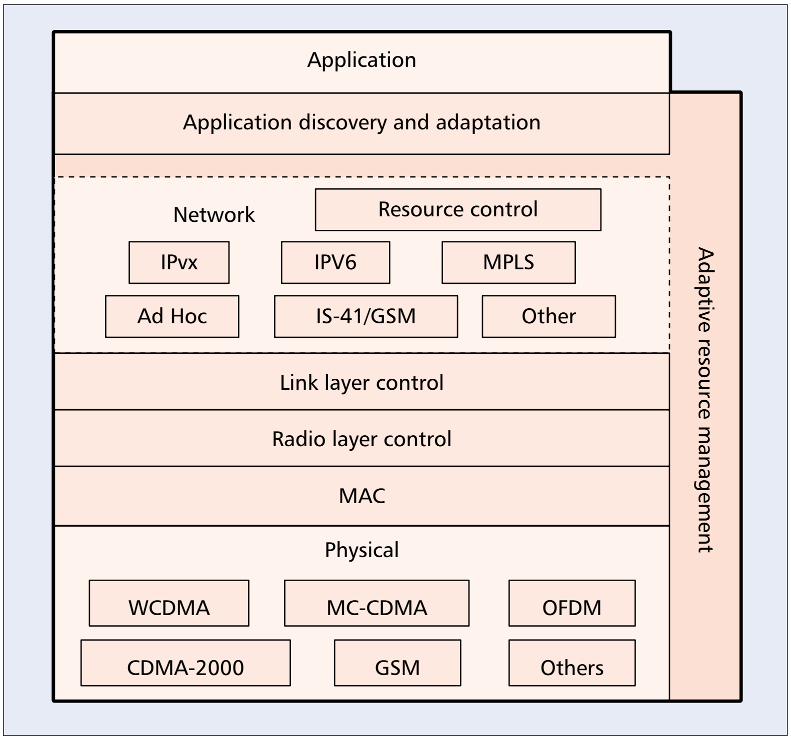


Figure 5. *Fully adaptive multilayer architecture.*

in NextG. These are **seamless integration**, **a high-performance physical layer**, **flexible and adaptive multiple access**, and **service and application adaptation**.

Seamless Integration — An IP-centric architecture is needed, with intermediary adaptation layers initially but with access and service technologies natively matched to it over time. This was discussed above and we will not dwell on it further.

High-Performance Physical Layer — New high-performance physical layer technologies are needed to provide 50–100 Mb/s, and to go as high as 1 Gb/s. As we go to these larger data rates the channels become truly broadband — the coherence bandwidths become a smaller percentage of the channel bandwidths, thus requiring more complex multipath processing to deal with the greater number of resolvable, but random, multiple paths. With the option of allowing frequency access or blocking schemes, orthogonal frequency-division multiplexing (OFDM)-type techniques (including, e.g., MC-CDMA and other OFDM forms) become more attractive as bandwidths and data rates grow. OFDM approaches can better handle larger numbers of resolvable paths [8], and can allow for fully adaptive frequency channel control. In addition, related approaches are possible, permitting channel capacities closer to the Shannon limit in the power-spectral efficiency plane, involving higher-level modulations as well as coded modulations, and more efficient coding schemes. Better spectral efficiencies in terms of bits per second per Hertz and power efficiencies in terms of the bit error rate (BER) vs. E_b/N_0, even in non-Gaussian environments, are the goal. Furthermore, advanced processing techniques like multi-user detection (MUD) [9], which involves the use of nonorthogonal multiple access, and other approaches to approximate maximum likelihood detection in an interference, or multi-user, environment, can also help us attain higher spectral efficiencies. Also in this technical area are the space-time coding techniques and the options available with smart antennas, all providing higher spectral efficiencies through better spatial reuse.

Flexible and Adaptive Access — But new and more efficient physical layer technologies will require more adaptability. The ability to match the available modulation/coding approach to the available link quality provides another dimension to obtaining the best performance. Fast adaptation, at every level and for every resource possible, across multiple layers, is needed to best meet the demands of higher data rates in the variable channel conditions typical of a wireless environment. OFDM approaches can be improved by adaptation to the channel conditions, and the same is true of the selection of modulation and coding schemes. Link-aware rates and access will optimize the available radio resources to the environment. Figure 5 depicts a multilayer architecture with fully adaptive layers, and with multilayer resource management. Other architectures may be conceived that provide cross-layer functionality.

Thus adaptability can be exercised in spectrum utilization (*smart spectrum*), in the physical layer (the *waveform* — modulation and coding — and the *multiple access approach*), at the MAC and link layers (e.g., by selecting the degree of dedicated vs. shared channel assignment dynamically), at the network and transport layers, and in applications and services. From centralized or hierarchical architectures an evolution toward ad hoc networks can be used to provide more flexibility in network access, routing, and end-to-end transport. Software radio is one technology that aims to allow this flexibility, but other technology developments are also required.

Service and Application Adaptation — Adaptation to the user and service needs is also desirable. Multiple access points and switching points, with distributed intelligence such that every wireless element can control how best to use its resources, is the capstone functionality that ties the three other factors described above to provide the best services.

ADAPTATION

Multiple levels of adaptation are a key principle in the capabilities and performance features NextG technology will be called upon to provide. **Service and application adaptation** will be necessary to provide the desired services at the appropriate QoS. It is theoretically anathema to the communications community to design a system that requires the layers above the transport layer to carry out any communications function. That would presumably eliminate the modularity inherent in a layered structure. But as is also common in most architectures, adaptation layers are provided to permit non-native payloads to use the transport and lower-layer functionality.

An **application discovery and adaptation layer**, as indicated in Fig. 5, serves a similar function. But it also goes beyond the usual convergence layer — it provides both adaptation to the available communications resources, including radio and channel, and includes the ability to discover applications that may be of value. The former is illustrated with the concept of channel adaptive source coding, where the source data rate being offered may vary, in this case in response to channel capacity and delay conditions. It is a form of user adaptation to the communications resources available. It includes a degree of negotiation between user needs, based on settings and offered load options, and communications resources availability, which could also include variable pricing options. Application discovery provides an ability to look for useful applications that the user or system finds of value. This is illustrated by the search for, and discovery of, functions such as location-based updates of user-friendly information such as roadside restaurants or service stations. Indeed, businesses can use wireless technology to enhance offerings or even create whole new businesses — for example, the notion of service stations could be greatly expanded with easy information services available to mobile users. Discovery allows the user module to look for what it wants and ignore the rest. It can be implemented using various technologies such as mobile agents or Java. It is shown below the application layer because the discovery includes the negotiation of communications services, such as negotiating for communications resources (e.g., data rates, QoS). It is only once the communications resources are available that the applications can run. A different applications service provider may provide the same application with fewer required communications resources, and the discovery layer can then select. This could be a natural market driver for efficient applications.

In the communications process resources need to be assigned and managed, and this needs to be done over an extended period of time. As applications and channel availabilities change, a complex management function needs to control the resources. This **adaptive resource management** (ARM) and control needs to be aware of the multiple layer capabilities and states. If it knows the desired loads and the channel and radio resources, it can manage up and down the multilayer structure. It decides and controls the activities, adjusting parameters and functions as needed to optimize desired features such as QoS, throughput, power utilization, or possibly some overall cost function. It is naturally a multilayer function. Multilayer controls are not unknown in wireless communications. In both 2G and 3G standards the radio resource management (RRM) function acts from the network layer down to the data link and physical layers, since the wireless physical resources are critical and controlled directly without intermediate layers. A null intermediate layer can always be defined. The ARM in NextG will be a much more complex function. It will need to provide:

Dynamic management of the allocated spectrum. This would include dynamic spectrum assignment (DSA) over a set of access points and user devices (generically labeled wireless nodes), as well as the management function at the individual node. DSA could involve functions provided by an application discovery or by higher layers. Online, including over the air, automated spectrum sharing and trading facilities could be involved.

Dynamic management of the multiple access schemes. Channels in NextG are expected to include frequency-division multiple access (FDMA) frequencies, time-division multiple access (TDMA) time slots, and code-division multiple access (CDMA) codes, as well as hybrid and new concepts. Already wideband CDMA (WCDMA) time-division duplex (TDD) allows TDMA/CDMA time slots/codes as a resource unit. In 4G more complex frequency/slot/code/space schemes can be provided, where the multidimensional resource space can be assigned dynamically. A "soft" channel is a more meaningful term when the resource assignments are multiplexed and vary dynamically. The timeframes over which variations are permitted is a subject for research, where multiple access efficiency for a variety of traffic types and conditions may lead to different timeframes for different traffic categories.

Dynamic soft channel management. For each soft channel resource unit there will be a need to control the modulation and coding functionality as well as to provide parametric control over constellation sizes, power levels, code sizes, channel measurements, and other related functions. This is similar to current RRM, except that the allowed control units can include a selection of type (e.g., modulation type), not just parameters, and vary on a faster timeframe. Inherent in this is a much greater degree of flexibility in the radio resources being managed, and the channel transmission options.

Dynamic layers and fast adaptation will be required at every layer. Each layer will have a number of technologies it may support, as indicated in Fig. 5. Each layer must also have the ability to provide the adaptation required by the ARM. Thus, at the physical layer multiple modulation, coding, and multiple access schemes may be available. Each of those needs to have the ability to be switched in quickly. Fast synchronization and parameter modifications will be necessary. Each layer must also provide the support for the peer entities at transmitter and receiver nodes to coordinate their operations if it is to be truly adaptive. Thus, the MAC and higher layers may need to include signaling information, but to do so in a capacity-efficient way — with either embedded signaling, out-of-band signaling, or, if possible, with distributed coordination mechanisms where some decision logic may provide inherent coordination. This latter approach can be a promising research area. At networking and higher layers adaptation to traffic conditions, routes, end-to-end QoS, and application requirements requires efficient new adaptation mechanisms and protocols. Both centralized and ad hoc networking need to be considered. The capability of each layer to adapt, by providing both options and parameters that may be selected as well as the mechanisms for adaptation, goes far beyond current approaches to select

In the communications process resources need to be assigned and managed, and this needs to be done over an extended period of time. As the applications and channel availabilities change, a complex management function needs to control the resources.

Recently a greater degree of programmability is being made available on devices that are nearly as inexpensive as fixed function devices, and software infrastructures to control these are emerging. A number of companies are making baseband processors available that include greater flexibility than ever before.

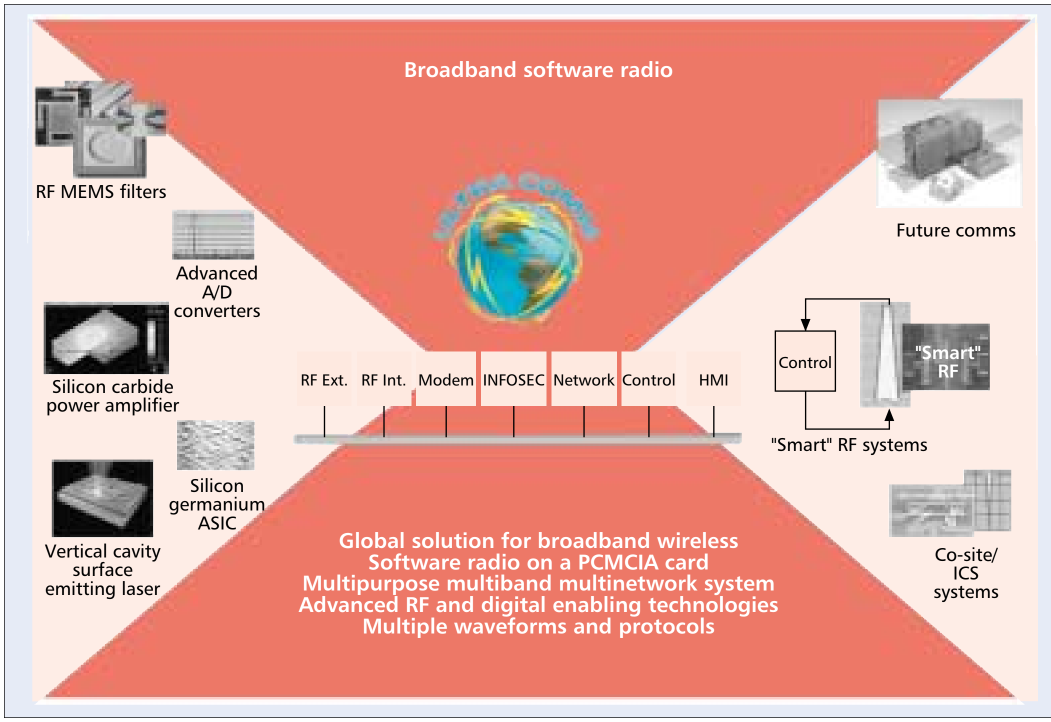


Figure 6. *Ultra Comm software radio architecture.*

various parameters at each layer. We call this *microadaptive©* to emphasize that although global and higher layer needs may request certain functionality from each layer, the adaptation mechanisms involve finer resolution of the selections and options. The dimensions of the adaptation will range to both larger domains (e.g., dynamic spectrum assignment and application adaptation) and smaller ones (finer resolution at each layer), up and down the multiple layers.

SOFTWARE RADIO AND SMART RADIO

A number of technologies will need to advance in order to have a basis for the capabilities described above. In designing for adaptation the logical functions and coordination mechanisms will need to be provided. In addition, a systems architecture that is better suited for the extreme levels of adaptation expected will be needed. The systems architecture needs can be matched to concepts in software radios [10, 11] and enhanced concepts variously called smart radio or cognitive radio [11]. Software radio prototypes exist, and concepts as envisioned in a number of papers and development activities are leading toward smart radio. The central tenet of software radio has been redefined into software defined radio (SDR): a radio with enough programmability, "enough" a purposefully loose term. The SDR Forum [12] has been an industry force in both promoting SDR and providing a basis for working definitions and terms, as well as some standards. It is all intellectually due to the programmability inherent in digital signal processing, and general-purpose logic, field programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), digital signal processors (DSPs), and other programmable devices continue to provide new options in the evolution of SDR. What is truly critical here, though, is the ability to easily and inexpensively (again, purposefully vague) modify the signal processing steps, and thus provide a different communications scheme. It is generally true that the need to process signals continuously at relatively high speed and at the lowest possible cost has typically led to a selection of the lowest-cost implementation technology, and specific modulation and coding schemes with only a certain amount of parametric options, not to a true SDR. Recently a greater degree of programmability is being made available on devices that are nearly as inexpensive as fixed function devices, and software infrastructures to control these are emerging. A number of companies are making baseband processors available that include greater flexibility than ever before. Baseband chipsets able to carry out WCDMA and GSM, or CDMA2000, CDMA1, and AMPS, or 802.11b, WCDMA, GSM, and one or two other mobile protocols, are emerging. There is no apparent near-term limit to the evolution of programmable signal and baseband processors, nor to the software infrastructures.

The situation is less clear on the RF side. RF devices involve complex and not easily reproduced frequency, bandwidth, noise level, intermodulation, and other electromagnetic effects. Thus, RF front-ends and ASICs cannot be as integrated or standardized as baseband digital processors. Efforts toward direct conversion to digital are accelerating, as are other technologies involving single or double conversion, but a clear best path is still elusive. For NextG the ability to work broadband will be necessary. Not only will there be a desire for working bandwidths beyond 5–20 MHz as possibly envisioned for 3G+, but there will also be a need to have true broadband functionality: the ability to work across a wide range of the frequency spectrum. One example of a prototype that achieves this is Raytheon's Ultracomm radio, an SDR designed for operations over frequency ranges that include 600–2800 MHz and can also go down to 20 MHz. Figure 6 depicts the Ultracomm architecture and concept, as well as some of the enabling technologies. Baseband or instantaneous bandwidth is currently set for 25 MHz, with 60 MHz and higher planned for the future. Figure 7 depicts the form factor for the Ultracomm radio, along with some features.

SDR technology continues to evolve. Hardware architectures, for both the baseband and RF sides, continue to improve, and although there is churning, standard technologies may not be too far off in the future. The availability of inexpensive SDR platforms for a multiplicity of wireless applications will be one of the enablers of NextG. It will provide a platform for adaptability. Furthermore, advances beyond that to Smart Radio will improve the opportunities for NextG.

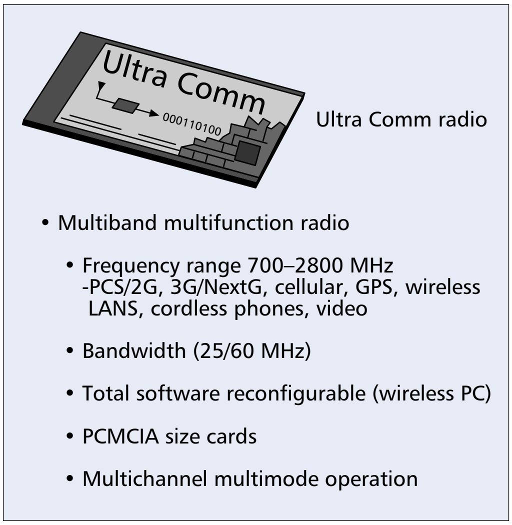


Figure 7. *Ultra Comm software radio form factor and key features.*

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ADVANCED ADAPTIVE WAVEFORMS AND PHYSICAL LAYER

The higher data rates expected in NextG will necessitate modulations and codes beyond DSSS and Turbo coding currently designed for 3G and 3G+. OFDM [7] and related modulation and multiple access schemes are emerging as a possibly preferred set of technologies.

In OFDM multiple coherent subcarriers are modulated and codes are used to insure that encoded bits can be decoded even if some of the subcarriers arrive at a very low $E_b/(N_0 + I)$. Also, OFDM is inherently more resistant to intersymbol interference (under expected multipath delays a cyclic extension is added), and frequency diversity is automatically provided. Furthermore, adaptability to interference conditions can be implemented on a subcarrier-by-subcarrier basis. Concerns such as those about frequency synchronization and Doppler offsets under mobility conditions are being investigated, and there are possible solutions. In multipath, as the number of resolvable paths in a channel increases beyond more than a few, OFDM modulations adapt easier than DSSS. OFDM simply multiplies each subcarrier's signal by a single complex number representing the inverse of that subchannel estimated transfer function. DSSS, on the other hand, has to estimate and implement a larger number of Rake fingers, since the multipath delay spread involves more fingers on a higher-data-rate channel. Variations of OFDM include MC-CDMA and other coded schemes. MC-CDMA applies a spreading sequence on the frequency domain. Each subcarrier can then be modulated and coded, with data rates adaptively determined to maximize overall BER. Higher-level modulations can be used in some subcarriers and not in others. The combination of frequency subcarriers and DSSS also allows for a hybrid FDMA/CDMA. In fact, time intervals can also be used for multiple access, so a TDMA/FDMA/CDMA hybrid is possible. Research and innovations in this area are expected to continue, as is the search for the best combination of multiple access scheme, modulation, and code. NextG adaptability would involve optimizing the selected hybrid scheme and its parameters dynamically based on channel performance metrics such as BER. A channel would permit the highest rate possible compatible with its current condition.

Also needed are space-division multiple access techniques and smart antennas, including space-time coding techniques. In all cases, fast adaptation to the channel and traffic conditions is the key to providing the needed QoS.

QOS, ADAPTIVE NETWORKS, AND UNIVERSAL ACCESS NODES

It is more than reconfigurable radios and advanced physical layer technologies that are needed. It is also adaptive networks, since adaptability and convergence of the various access technologies will require the networks to provide access to a number of radio technologies, and in fact to be a part of the adaptation process, while providing applications and services at QoS levels users expect. QoS concepts will continue to evolve toward approaches where QoS is parametric (e.g., delay and percentage of lost packets), and may be selected or negotiated between the user, the network provider, and the application or service provider.

Network concepts and architectures will evolve to those that include dynamic adaptation to traffic and QoS needs in light of multiple access technologies. This will involve changes at all layers and indeed across layers. Many of the physical layer topics were covered above, as well as some of the needed changes in the MAC and link layer, and the networking and higher layers. Traffic and QoS adaptability will require that information be used across layers. MAC and routing issues, as well as the technologies for ad hoc and self-configurable networks will have the biggest impact. Flexible dynamic networking is an area of active research interest [13].

The concept of plug-and-play base stations [4] has been evolving to one of universal base

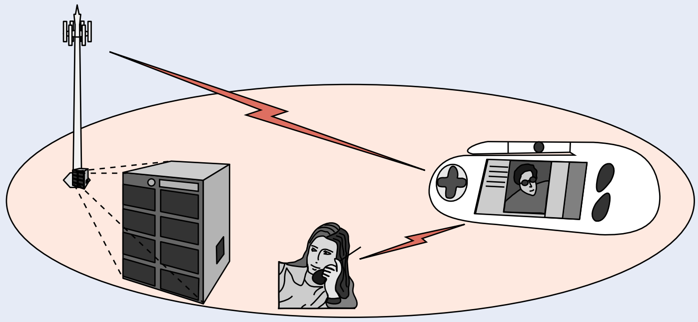

Figure 8. *Universal access node.*

stations and access points, to wireless ad hoc networking and eventually to flexible dynamic networking [13]. Figure 8 depicts a universal base station or access node. In NextG a universal access node would be able to implement a multiplicity of access technologies, and provide for a wireless multinetwork where those technologies are dynamically selected based on a best match to user needs and available resources. Beyond that, as access and network technologies become more adaptable and inexpensive, and self-configuring network concepts and technology provide architectural and control alternatives in network organization, deployment, and management, it becomes possible to envision the NextG adaptive network.

CONCLUSION

We summarize the drive toward ubiquitous wireless communications and services, and describe some of the technologies that provide a basis for the evolution toward next-generation wireless. These include dynamic and adaptive systems and technologies that provide a new paradigm for spectrum assignment and management, and smart radio and adaptive networking. Technologies involving adaptive and highly efficient modulation, coding, multiple access, media access, network organization, and networking will provide ultraconnectivity at high data rates with effective QoS for next-generation wireless.

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BIOGRAPHIES

ROBERT BEREZDIVIN [M] (rberezdivin@raytheon.com) is chief scientist at Raytheon's Information and Advanced Systems, in Falls Church, Virginia. He oversees and coordinates its technology strategies and R&D, including those in wireless communications, for both defense and commercial applications. He also leads its activities in NextG, including innovative developments in high-performance radio and access technologies and networks, SDR technologies and applications, adaptive modulation and coding, and adaptive and ad hoc networks. He oversees new business and program activities with advanced technology customers, including government laboratories and the Defense Advanced Research Projects Agency, and has been instrumental in creating new business and technologies for the company. He received his B.S. and M.S, degrees from the University of Florida, and his Ph.D. from the University of California at Berkeley. He has worked in advanced signal processing, radars, and communications systems for over 25 years, and has been involved in mobile wireless systems for over 10 years. His interests include both advanced technologies as well as the systems to implement them. He is also an adjunct professor at the University of Maryland and George Mason University. He is a participant in the World Wide Research Forum, and speaks out on next- generation wireless concepts and technologies. He is listed in various Who's Who. He is a member of Sigma Xi.

ROBERT BREINIG is an engineering fellow at Raytheon's Information and Advanced Systems, Falls Church, Virginia, where he has specialized in the development of advanced wireless communications systems for military applications and commercial spinoffs for over 18 years. He has been a principal investigator for several Defense Advanced Research Projects Agency programs where he has been engaged in developing technology for software radios, advanced waveforms, and ad hoc wireless networks. His interests range from chip-level technologies through real-time operating systems, wireless protocols, coding and modulation theory, RF propagation, software radios, and system architectures. He holds a B.S. degree in physics from Carnegie Mellon University. Previously he created and directed Motorola's commercial wireless data products group in Schaumburg, Illinois. He was chief engineer for the development of a North American continental wireless data network for IBM and Motorola, which evolved into the ARDIS network, and is now the terrestrial component of the Motient network.

RANDY TOPP is a product line director at Raytheon's Information and Advanced Systems, Falls Church, Virginia, where he is program manager for the development of advanced wireless communications for military and commercial applications. He also directs several programs in command, control, and communications (C3) and for the Defense Advanced Research Projects Agency. He holds a B.A. degree in economics from Vanderbilt University, and M.S. degrees in electrical engineering and space systems technology from the Naval Postgraduate School.