These days everyone is talking about 5G: 5G phones, 5G networks, 5G appliances, and even 5G-ready vehicular networks. So what is 5G? What is going to happen to my (flip) phone? My wireless router at home or an access point at my (small) office? My all-new electric car? Do I have to buy a whole new set of devices for my car, office, and home? Will my phone continue to work at Starbucks and at the airport with free Wi-Fi? Are there new standards coming up for these gadgets to work on the old and the new networks?

Even if you are a casual user of the Internet looking for advances in communication technology, you will come across an alphabet soup (and numbers) with acronyms such as ITU-R, 802.11, 3GPP, IoT, ad, and ah. What about all the other TLAs (three-letter acronyms) I keep reading about in technical journals, magazines, and sometimes even the business media?

Well, you don’t have to wonder anymore, nor do you have to wonder very far. Adrian Stephens is a member of the Standards Education Committee (SEC) and the Editorial Board of this eZine. He is also very active in the wireless standards development community. In fact, he chairs the IEEE 802.11 working group, so you are going to hear about these topics straight from the horse’s mouth—literally!

Adrian has prepared a 15-minute video that explains the role of many of these standards, their respective organizations, and their interaction with each other. And at the end of his video talk, he introduces the other papers and articles. For many of our regular readers, Paul Nikolic’s article will resonate well. Not only has he contributed to past eZines, but as the Chair of the entire IEEE 802 working group, he also has the best seat in the industry to tell you about the importance of standards in networks. Many of you will then move on to the focused articles and research papers to learn about these standards and related activities. We have a great collection from expert contributors:

- Coexistence of Content-Centric Wireless Network (CCWN) and Traditional Cellular Networks, by Bitan Banerjee, et al.
- Interworking of mmWave and sub-6 GHz Access Technologies for 5G Multi-Connectivity, by Kishor Chandra, et al.

IEEE’s Standards Education Program is committed to:

- Promoting the importance of standards in meeting technical, economic, environmental, and societal challenges.
- Disseminating learning materials on the application of standards in the design and development aspects of educational programs.
- Actively promoting the integration of standards into academic programs.

By Yatin Trivedi, Editor-in-Chief, IEEE Standards Education e-Magazine

This online publication, available at http://www.standardsuniversity.org/e-magazine/, is sponsored by the IEEE Standards Education Committee, a joint committee of the IEEE Educational Activities Board and the IEEE Standards Association.

The purpose of the e-Magazine is to help raise awareness of standards, show the importance of standards, present real-world applications of standards, and demonstrate the role you can play in the standards development process. Knowledge of standards and standards activities can help facilitate your professional engineering practice and improve technological developments to meet the needs and improve the lives of future generations.

The March issue of the IEEE Standards Education eMagazine explores the work that has been done and is currently taking place around Standards and 5G. Certain articles are included here, and the abstracts are shown for the rest.

Featured Videos: Adrian Stephens (Member of the eZine Editorial Board and the Chair of the IEEE 802.11 Working Group) has prepared a 15-minute video that explains the role of many of the new wireless standards coming up, their respective organizations, and their interaction with each other. The video is available on the website of the IEEE Standards Education e-Magazine (https://www.standardsuniversity.org/e-magazine/). Adyutash Dutta (IEEE 5G Initiative Co-Chair and Director of Technology at AT&T Labs), presents an overview of the IEEE 5G Initiative that was launched by the IEEE Future Directions Committee on August 29, 2016, in Princeton, NJ, USA. Currently there are 21 IEEE societies contributing to this initiative. The video is available on the website of IEEE.tv (https://ieeetv.ieee.org/conference-highlights/ieee-5g-initiative-overview-by-adyutash-dutta-at-ieee-connectivity-jam-2017).
Coexistence of Content-Centric Wireless Network (CCWN) and Traditional Cellular Networks

By Bitan Banerjee, University of Alberta, Sibendu Paul, Purdue University, Amitava Mukherjee, Globysyn Business School

Abstract: Enabling content-centric network (CCN) features over a cellular network can significantly reduce mobile data traffic and support upcoming 5G. However, traditional cellular networks follow a host-centric network architecture rather than the content-centric architecture. Moreover, supporting CCN-specific features, such as multicast and broadcast of content to multiple users, searching a possible content source in a wireless environment is extremely challenging due to constraints of limited power and user mobility. The primary question remains, how to distinguish between CCN packets and normal cellular network packets? Is it possible to enable these features at router level? This article explores several technologies and packet formats to support coexistence of CCWN and traditional cellular communication.

Interworking of mmWave and sub-6 GHz Access Technologies for 5G Multi-Connectivity

By Kishor Chandra, Delft University of Technology, Marco Mezzavilla, NYU Tandon School of Engineering, R. Venkatesha Prasad, Delft University of Technology, Periklis Chatzimisios, Alexander TEI of Thessaloniki and Bournemouth University

Abstract: The fifth generation (5G) communications technologies target diverse applications ranging from automotive, industrial communications, smart health, agriculture, entertainment, public safety and even tele-surgery. These applications have diverse requirements that include very high data rates (in order of multi-gigabit per second), ultra-high reliability (99.999999% availability) and extremely low latency (as low as 1 ms). To fulfill these requirements, numerous new candidate technologies such as the use of millimeter wave frequency bands, licensed assisted access (LAA) in unlicensed bands, non-orthogonal multiple access (NOMA), cloud radio access (C-RAN) and massive multiple input multiple output (massive-MIMO) have emerged. It is evident that many 5G applications will be served by multiple radio access technologies in tandem to fulfill the diverse application requirements while ensuring the most efficient use of radio resources. For example, a remote-surgery application would require (i) low-latency radios to transport haptic feedback, (ii) very high data rates to transfer 360 immersive videos, and, finally, (iii) ultra-high reliable links. This aggregate set of performance targets can be met by opportunistically activating multiple radio components, at different frequency bands, to match the specific communications requirements.

Making 5G NR a Commercial Reality—A Unified, More Capable 5G Air Interface

By Wanshi Chen, Qualcomm Research, Qualcomm Technologies

Abstract: There is insatiable demand for mobile broadband. In December 2017, as part of 3GPP’s Release 15, a first version of 5G new radio (NR) was declared complete. The first version is a non-standalone (NSA) version where a 5G NR carrier leverages 4G LTE for coverage and mobility while enabling a fast introduction of 5G NR to enhance user plane performance and efficiency. The standalone version of 5G NR is expected to be ready by June 2018. 5G NR is essential for next generation mobile experiences, providing fiber-like data speeds, low latency for real-time interactivity, more consistent performance, and massive capacity for unlimited data. In addition, 5G expands the mobile ecosystem to new industries. It provides diverse services including traditional enhanced mobile broadband (eMBB), new verticals such as massive machine-type communications (mMTC), ultra-reliable low-latency communications (URLLC), and cellular vehicle-to-everything (C-V2X), and scalability to address a tremendous variety of requirements. It covers diverse spectra, including sub-6 GHz and millimeter wave (mmWave), in order to get the most out of a wide array of spectrum bands/types. It also supports various deployments, from macro to indoor hotspots, with support for a range of topologies.

The Road Towards Faster, Simpler, and Smarter Test Equipment for mmWave Products

By Jorge S. Hurtarte, LitePoint

Abstract: The demand for millimeter wave products is quickly moving into the consumer market place. Historically, both Wi-Fi and cellular services have been operating in the crowded frequency bands under 6 GHz. Over the next few years, we expect to see new wireless communications standards widely adopted into new products (including smartphones, head-mounted displays, hot spots, etc.) that operate at mmWave frequencies over 24 GHz. For example, the IEEE 802.11 working group has released two new standards, 802.11aj and 802.11ad, operating in the 40 GHz and 60 GHz unlicensed mmWave bands respectively, and is pursuing a new 802.11ay standard in the 70 GHz band. In addition, the 3GPP standards organization has recently introduced a 5G new radio (NR) cellular standard capable of initially operating in the 28 GHz and 39 GHz mmWave bands as well as sub-6 GHz bands.

How Well-Positioned is IEEE 802.11ax to Meet the IMT-2020 Performance Requirements?

By Rakesh Taori, Phazr Inc.

Abstract: The industry is buzzing with activities related to the next generation of wireless communications technology—5G! In parallel, the telecoms industry as a whole—a service providers, vendors, academia, and standards-setting bodies—are working under the umbrella of IMT-2020 to define exactly what 5G will be. The term “IMT-2020” was coined in 2012 by the International Telecommunication Union Radiocommunication Sector (the ITU-R) and refers to an international mobile telecommunication system with a target date set for 2020. The ITU-R Study Groups develop global standards (recommendations) and the technical bases for decisions taken at the World Radio Congress (WRC). Relevant to our discussion here is Working Party 5D (WP5D), which operates under Study Group 5 (SG5) of the ITU-R. WP5D is responsible for the overall radio system aspects of international mobile telecommunications (IMT) systems, comprising the IMT-2000, IMT-Advanced, and IMT for 2020 and beyond.

Full Articles

5G Standards in IMT-2020 and Elsewhere

By Roger Marks, EthAirNet Associates

What is 5G? Who knows?

In my observation, a most frequently asked question of the last few years, not only in the fields of telecommunications or standardization, has been “What is 5G?” One web search turns up about 73,000 matches for that phrase. Yet a brief literature survey indicates that the number of answers may be of the same order of magnitude as the number of times the question has been asked. This brief article does not attempt to answer the question in depth but simply provides a perspective.

Gs and Re-Gs

5G is intended to represent something beyond 4G, which followed 3G and indicates the fourth generation of cellular wireless network technology. Earlier generations of cellular were identified in retrospect as 1G and 2G, but those monikers were
not popular at the time. However, the industry focused on the term “3G,” and it became a hit, spawning a successful sequel in 4G.

Many technology industries evolve, but not all with the discrete cadence of the cellular industry. The business is heavily dependent on interoperability, and the various facets of the industry—including components and devices, software and networks, engineering expertise and marketing—are all orchestrated in a worldwide symphony. Cellular operators, which are limited in number, stable over many years, and often strong players in their markets, coordinate closely with a relatively small community of major vendors to steer the technical and market evolution. This evolution is mediated by standardization, particularly through the 3rd Generation Partnership Project (3GPP), a partnership of regional standards-developing organizations that has retained its original name while its focus has turned toward successive generations.

**Regulatory Mediation**

The rollout of new cellular standards is not only tied to industry coordination but also tightly bound by international regulations. National-scale cellular providers operate using radio spectrum that is exclusively licensed for their use by national administrations. Global harmonization and global circulation of mobile devices that operate in such restricted radio bands hinge not only on technical standards but on compatible regulatory environments. The key international requirements are laid out in the Radio Regulations hammered out in a series of World Radiocommunication Conferences (WRCs) of the Radiocommunication Sector (ITU-R) of the United Nations’ International Telecommunication Union (ITU). Much of the content of the Radio Regulations is technologically neutral. However, in the 1990s, the ITU Radio Regulations began to “identify” spectrum for potential use by “International Mobile Telecommunications (IMT),” where IMT is specified by a series of ITU “Recommendations,” which are standards. This “identification” is not a mandatory aspect of the Radio Regulations; identification is “for those administrations wishing to deploy IMT” and is intended to provide guidance for regulators and global equipment manufacturers regarding appropriate radio bands and technologies. The combination has proven very effective in providing guidance to the industry and has been successful beyond any parallel in the history of technology.

As the industry has succeeded, it has, time and again, faced the need for more spectrum in which to operate. Long-term spectrum demand has been channeled into a series of requests for additional spectrum for modernized technology. Roughly once per decade, the cellular industry and ITU have formulated the concept of a new generation of technology that promises greater opportunity and is accompanied by additional spectrum identification. In 2000, significant spectrum was identified for technology and was specified as “IMT-2000” in ITU-R Recommendation M.1457. That recommendation incorporates external standards, such as those of 3GPP, and these are identified through the unique IMT concept of “Global Core Specifications.” Through an IMT-specific activity (currently known as ITU-R Working Party 5D), Rec. M.1457 has been maintained and updated annually or biennially, pointing to evolving 3GPP specifications as well as some others.

**IMT-Advanced**

Although various technology alternatives were adopted in IMT-2000, the most striking technology thread was multiple access via CDMA. As the decade proceeded, ITU-R undertook the development of a new generation of IMT, known as “IMT-Advanced,” and began intensive discussion on identification of additional IMT spectrum. Meanwhile, alternative technologies rose to prominence, particularly suited to the increasing demands for broadband data services. In the IEEE 802 LAN/MAN Standards Committee, IEEE Std 802.11 introduced OFDM in 1999. This became very successful in the marketplace, particularly beginning with the 802.11g amendment in 2003. IEEE Std 802.16e-2005, which was deployed by commercial cellular operators in several countries. That WirelessMAN-OFDMA technology was adopted into IMT-2000 in 2007. In 2006, IEEE 802 authorized a new project with the specific target of meeting the IMT-Advanced requirements. The result, later published as WirelessMAN-Advanced in 2005, was a new project with the specific target of meeting the IMT-Advanced requirements. The result, later published as WirelessMAN-Advanced in 2002, was one of two technologies (both OFDMA-based) incorporated into IMT-Advanced in ITU-R Rec. M.2012. However, WirelessMAN-Advanced was not deployed in the cellular market, losing out to 3GPP’s LTE.

ITU-R approached the new technology by broadening the concept of IMT to include IMT-2000 and IMT-Advanced (which would both continue to evolve) as well as additional varieties of IMT to be developed in the future. The 2012 WRC identified additional spectrum for IMT, replacing “IMT-2000” with the more general term “IMT” so as not to connect specific spectrum to specific versions. The 2015 WRC nonetheless added IMT-2020 to the lexicon as the next evolution under the IMT umbrella.

**What Is 4G?**

Before we all began asking what 5G is, this same question arose regarding 4G.

OFDMA was the striking common technology thread in IMT-Advanced and denoted a major demarcation of a new generation. It was, and remains, technically appropriate to identify the OFDMA technology as the mark of 4G. Still, as noted, OFDMA had found its way into evolutions of IMT-2000, and opinions varied as to how closely the meaning of 4G should be tied to IMT-Advanced.

Even ITU struggled with the distinction between 4G and IMT-Advanced. During the development of the work, ITU-R Working Party 5D had explicitly decided not to use the term “4G.” However, in a 2010 press release announcing IMT-Advanced, ITU-R said that “LTE-Advanced” and “WirelessMAN-Advanced” were “accorded the official designation of IMT-Advanced, qualifying them as true 4G technologies” [1]. This stance conflicted with the broader consensus of the WirelessMAN (and even some updated CDMA-based) technologies as 4G. Indeed, even in 2018, many LTE implementations lacking the suite of LTE-Advanced features are recognized by industry and the public as 4G. ITU soon quietly backed off its stance that IMT-Advanced was the mark of true 4G. Currently, ITU states that “the term ‘4G’ remains undefined… ITU cannot hold a position on whether or not a given technology is labelled with that term for marketing purposes” [2].

The perspective of this article is that the Gs are not standardized terms or certification marks, and neither the ITU nor any other entity establishes their requirements. Most IMT-2000 technologies can be characterized as 3G or higher, and the IMT-Advanced technologies can be characterized as 4G or higher. However, the terminology is loosely used, even within the cellular industry, and no entity determines the official definition. ITU recognition provides a sound credential for a G claim, but technologies not in any way represented in ITU may nevertheless be fairly identified with a G.

**IMT-2020**

ITU-R began planning for IMT-2020 in 2012, and a set of Recommendations and Reports were prepared by Working Party 5D, including the vision, framework, and objectives document (Rec. ITU-R M.2083) that was referenced by WRC 2015. This
activity resulted in some new signals about 5G trends. In particular, as a follow-up to WRC 2015, an agenda item (1.13) was added to WRC 2019 to consider identification of spectrum for IMT in a number of higher-frequency bands ranging from around 24 to 86 GHz, signaling that IMT-2020 is partially related to millimeter-wave radio. Further, Rec. ITU-R M.2083 indicated a much wider range of applications as compared to prior versions of IMT. In particular, IMT-2020 will be specified to address three “usage scenarios”:

1) enhanced mobile broadband (eMBB), extending the services provided by IMT-Advanced;

2) ultra-reliable and low-latency communications (URLLC), addressing applications such as industrial manufacturing, remote surgery, and controlled automobiles;

3) massive machine type communications (mMTC), considering a very large number of low-cost, low-energy devices typically transmitting a relatively low volume of non-delay-sensitive data.

These decisions indicated an intention to drastically expand the scope of IMT and, therefore, the breadth of applications to be supported within IMT-identified spectrum. This could be broadly understood to represent the notion that the cellular communications industry, including the operators and vendors, would expand their business beyond a focus on supporting handheld devices.

ITU-R has completed follow-up documentation specifying the IMT-2020 development process, schedule, technical requirements, and evaluation criteria, setting a proposal deadline during 2019 and planning to complete the IMT-2020 Recommendation by October 2020. 3GPP has already provided information regarding its intended submission.

The IMT-2020 requirements spell out an ambitious and challenging program for the cellular industry that certainly will demand many technical advances. If the current generation is 4G, then IMT-2020 invokes a new view of 5G or beyond. However, unlike 3G and 4G, which could be understood as extending applications of such technology, IMT-2020 is positioned as an application-expanding effort involving optimization of technologies in a variety of environments.

What Else Is 5G?
The vision of enhanced mobile broadband and an expanded set of wireless applications has stimulated not only the cellular industry but others as well. Some of the ambitions are individual and others are standardization based.

Within the IEEE, many activities relevant to 5G have arisen. IEEE has organized a coordination of those efforts as the “IEEE 5G” Initiative [3]. Many technical activities and fields of interest are represented there. The website identifies 5G as “next generation networking” which is clearly much broader than IMT-2020. The initiative compiles the “IEEE 5G and Beyond Standards Database” and supports an “IEEE 5G Roadmap” activity as well.

5G cannot be contained within ITU or any specific control group. Any endeavor that relates to a “generation” must represent some level of coordination of technologies and timeframes. A credible 5G will represent an integrated network specification set that could support a large operator deployment, be stable for the long haul, will support multiple applications and access technologies, and will evolve [4].

Outside the IEEE, other visions of 5G have been articulated. For example, CableLabs [5] has envisioned 5G wireless from the cable telecommunications industry perspective and sees IEEE and Wi-Fi technology standards as part of “the essential core of 5G.”

The Final G?
Technology industries typically evolve based on technical innovations that are driven from the bottom up, by new discoveries and newly practical implementations. The concept of a decade-long coordinated effort to plan and push out a new technology generation worldwide is an exceptional case. 3G and 4G cellular, and perhaps 5G cellular as well, are ideal examples of the exception. However, while 3G and 4G were focused on specific deployment scenarios—communicating to human beings via handheld devices—5G is anticipating a much broader role. With this broadened focus, it is difficult to envision 5G as a coherent set of products and services. As a result, it is easy to imagine that the variety of differentiated scenarios will fracture the market into a set of differentiated industries with separate players, business models, and cost structures. As a result, the upgrade timescales of those industries may vary as well. It may be difficult to coordinate these disparate industries with the kind of singular focus required to integrate global technology innovations into a decade-long mass action. As a result, 5G may be the last of a royal lineage.

References

Biography
Roger B. Marks (F) (roger@ethair.net) received his Ph.D. degree in applied physics from Yale University and is engaged with EthAir Network Associates. He has participated in IEEE 802 since 1998, serving during that time on the IEEE 802 Executive Committee and as Chair of the IEEE 802.16 Working Group. He was instrumental in efforts leading to the incorporation of IEEE Std 802.16 into the ITU-R’s “3G” IMT-2000 standard and its “4G” IMT-Advanced standard. He participates in the IEEE 802.11 Working Group, serving as Vice Chair of the Advanced Access Network Interface Standing Committee. He is also active in the IEEE 802 Working Group, serving as Technical Editor of IEEE Std 802z-2017 and the P802.1CQ project as well as participating in the IEEE 802 “Network Enhancement for the Next Decade” Industry Connections Activity (Nendical). He is a member of the IEEE Registration Authority Committee.

How IEEE 802.11 WLAN IS AN ESSENTIAL PART OF A PRACTICAL 5G CELLULAR NETWORK
By Joseph Levy, InterDigital, Inc.

This article provides some high-level architectural descriptions of a fifth-generation (5G) cellular network that contains an IEEE 802.11 wireless local area network (WLAN). There is no agreed-upon definition of what a 5G network is as various stakeholders have different definitions based on their perspectives. The Third Generation Partnership Project (3GPP), the cellular standardization community, defines 5G to mean the next generation of cellular technology (3GPP Release 14, 15, and 16 specifications). These releases are the specifications that 3GPP is developing to address the International Telecommunications Union Radiocommunication Sector’s (ITU-R) International Mobile Telecommunications 2020 (IMT-2020) requirements [1]. The general IEEE community has embraced a definition of 5G to be the advanced/nex-generation communications technologies that will contribute to defining next-generation networks [2]. To the cellular marketing community and the general public, it has been defined as the next advance in communications technology, following 4G (Long Term Evolution, LTE), which will “improve” everyone’s life. For this article, the 5G cellular network is understood to be the next generation network that will provide communications services for mobile devices: smartphones, tablets, and laptops. To connect these devices, it is assumed that the network will need to include multiple radio access technologies (RATs) such as IEEE 802.11-based WLAN.
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802.11 (WLAN) [9], commercially known as Wi-Fi and WiGig, and various 3GPP-defined wireless cellular technologies such as Enhanced Long-Term Evolution (eLTE) and New Radio (NR).

Please note that the example network architectures provided in this article are used to illustrate different ways of implementing an integrated 5G network. This set of examples is not intended to be complete, and actual implementations will vary as they will be customized to the network operator’s business and customer needs.

Many user applications and services need to have connectivity between the mobile device and application or service servers in order to function. Network technologies and radio access technologies (RATs) provide this connectivity by defining data bearers for these applications and services to use. The architectures described below manage and assign RAT resources to these bearers differently and, therefore, may have different efficiencies, flexibilities, and dynamic performances. However, they all attempt to achieve the same end goal of providing data bearers to meet user needs.

It is also assumed that the 5G network will provide data bearers that will connect mobile devices to various applications and services. These data bearers will use a RAT or multiple RATs connected to a 5G core network or a general wide area network (WAN) to provide these connections. The architectures shown are consistent with the planned 3GPP Release 15 specifications (June 2018) [1, 3], and [4]. To enhance the connectivity options of the 5G cellular network an IEEE 802.11 based WLAN is added. The inclusion of an IEEE 802.11-based WLAN is currently a reality in many existing 4G cellular networks as Wi-Fi-based internetworking, video streaming, and Wi-Fi calling are usually available to users with most mobile devices. It is also assumed that the 3GPP user equipment (UE) shown in the diagrams can support multiple RATs simultaneously (e.g., eLTE, NR, and Wi-Fi).

1. The first architecture connects the mobile device to the 5G core network by any or all of the three available RATs: eLTE, NR, or 802.11, as shown in Fig. 1. The 5G core network provides connectivity to application and service servers. In this architecture, the 5G core network is connected through the eLTE RAT, which then manages the data flows (solid line connections) over all the RATs: eLTE, NR, and 802.11. The eLTE Node B performs the bearer management to route the data to and from the mobile device through a RAT or combination of RATs. For data being sent via the 802.11 RAT the Node B can use the 3GPP specified LTE-WAN Aggregation (LWA) [5], [6] or LTE WLAN Radio Level Integration with IPsec Tunnel (LWIP) [4], [5] capabilities. Routing of data via the NR RAT is part of the planned 3GPP Release 15 specifications [1]. This architecture allows the eLTE Node B to make near “real time” splitting and routing decisions based on link performance of the available RATs. All non-access stratum (NAS) control signaling (dashed connection) is sent over the eLTE RAT. Note that there have been some discussions regarding 3GPP LWA/LWIP type aggregation for 3GPP NR. However, at this time, there is no 3GPP activity to create such a specification, though it may be considered in the future by 3GPP Technical Specifications Group (TSG) on Radio Access Network (RAN) [3]. If this 3GPP NR capability is specified, it will enable an alternate architecture where the NR Node B manages the aggregation of the RATs and provides the NAS control signaling. This alternative architecture will connect the 5G core network directly to the NR RAT (and not the eLTE RAT).

2. 3GPP TSG, Service and Systems Aspects (SA) is currently working to define a set of specifications for the 3GPP 5G system that will specify a common interface between the access network and the core network. This interface will integrate both 3GPP and non-3GPP access types [4], [8]. In this architecture, the 802.11 RAT is connected directly to the 3GPP 5G core network via a trusted or untrusted non-3GPP interface. The trusted or untrusted non-3GPP interface is currently being specified by 3GPP TSG SA [4]. As shown in Fig. 2, data bearers are routed or split by the core network over any or all the available RATs: eLTE, NR, and/or 802.11. This architecture allows the core network to optimize the data flows to and from UEs. Control is shown to be provided via the NAS access network, which is one probable configuration as the control signaling routing is also configurable by the 5G core network.

3. In the third basic architecture, shown in Fig. 3, a mobile device is connected through a single RAT, 802.11, to an 802.11 switched WAN that provides network connections to an application server, a service server, and a 5G core network (which may provide connectivity to additional application and service

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**Figure 1.** 3GPP LWA and LWIP integration of an IEEE 802.11 WLAN network within a 3GPP eLTE RAT.

**Figure 2.** 3GPP 5G core integration of an eLTE RAT, a NR RAT and an IEEE 802.11 WLAN network.

**Figure 3.** IEEE 802.11-connected mobile device connecting to the 5G core network and other services.
servers, not shown). The 802.11 wireless network can be connected to the WAN via a traditional 802.11 distribution service (DS) and a portal combination [9] or by a direct connection to an IEEE Std 802.1Q bridge [11, 12] via an 802.11 general link [10]. To allow applications and services accessible through the 5G core network, a connection to the 5G core network is provided via 3GPP-defined untrusted or trusted non-3GPP access [4], [8]. The bearers in this architecture are managed by the WAN management of packet flows through the network and/or the 3GPP 5G core network. Note that most UEs currently use a variation of this architecture to browse the internet, stream videos, and provide Wi-Fi calling when they are connected to the internet via Wi-Fi.

The high-level architectures described above provide an overview as to how 5G networks may be configured to leverage existing and future IEEE 802.11 WLAN RATS with existing LTE RATs and future eLTE/NR RATs so that the 5G goal of an always-on, high-speed wireless access network to support user applications and services on mobile devices can be met. To achieve this goal, it is essential to use both current and future deployed RATS and networks. Given the large and ever-growing number of installed IEEE 802.11 WLANs and the almost universal availability of 802.11 RAT in mobile devices, it is desirable to leverage these RATS to enable the deployment of 5G networks in a timely and cost-effective manner.

**REFERENCES**


**WHY ARE STANDARDS OF VALUE IN NETWORKS SUCH AS 5G?**

**BY PAUL NIKOLECH, IEEE 802 LAN/MAN STANDARDS COMMITTEE CHAIR**

The primary function of a network is to connect endpoints and allow information to flow between them. These endpoints can be humans or devices such as phones, tablets, sensors, automobiles, robots, drones, buildings, factories, etc. Ultimately, the number and type of endpoints are too numerous to list. Yet “the network” must connect them all, small and large, in a secure, reliable, consistent, and cost-effective manner. As a result, networks have grown into highly complicated systems that not only shuttle information around but also have the capability to monitor network health, automatically repair faults, measure usage, control access, and generate bills.

Today, these networks are assembled from a wide variety of components consisting of hardware and software elements that communicate using their own native protocol. These components include traditional wireline networks, cellular networks, satellite network, and wireless communications, which run on top of the Internet. The functionality and interfaces of each component must be very well defined and specified in order to allow multiple suppliers, chip vendors, system vendors, network engineers, and communications service providers to interconnect them in a predictable and reliable manner. These specifications can be proprietary/custom or open/standard.

Furthermore, these components are sourced from a wide variety of suppliers that likely do not have any formal interaction with one another. Yet these networks, built from an incredible array of components sourced from thousands of suppliers, work well and provide a high quality of service to their end users. How is this possible? It is because a rich library of performance and interface standards have been developed over the decades. These standards, which are agreed upon by the many standards development organizations, are one of the primary reasons these networks operate so well. Networks will always be dependent on well-defined standards, whether they are created internally via a propriety process or cooperatively via an open, transparent and consensus process.

The open transparent and consensus process practiced by the IEEE 802 Local Area Network (LAN) / Metropolitan Area Network (MAN) Standards Committee has proven to be a successful model, as demonstrated by the economical delivery of Internet services worldwide based on components conforming to the specifications defined by the collection of IEEE 802 standards. The IEEE 802 family of standards is but one of many that have been developed by similar standards development organizations such as the International Engineering Task Force (IETF), CableLabs, International Telecommunication Union (ITU), and European Telecommunication Standards Institute (ETSI) – 3rd Generation Partnership Project (3GPP).

These standards enable networks to grow, and this growth creates marketplace volume efficiencies. These efficiencies result in lower costs, which encourage more use of the network, which enables new uses that may not have been economically viable in the past. This in turn drives the network service provider to further grow the network, resulting in a virtuous cycle we find ourselves in today. 5G is a buzzword that I don’t care for much, but it has come to reflect that at a very high, gross level, networks are entering their next generation of growth. This growth has been partially but significantly fueled by the standards used to build almost every component, standards that networks conform to. That’s the value standards bring to 5G.

**BIOGRAPHY**

PAUL NIKOLECH has been serving the data communications and broadband industries for roughly 17 years, developing technology, standards, and intellectual property and establishing new ventures as an executive consultant and angel investor. He is an IEEE fellow and has served as Chairman of the IEEE 802 LAN/MAN Standards Committee since 2001. As 802 chairman, he provides oversight for 75 active 802 standards and the 50+ concurrent 802 activities in wired and wireless communications networking, 802 has over 750 active participants, and the many standards development activities and relationships between IEEE 802 and global/regional standards bodies such as ISO, ITU, and ETSI, regulatory bodies, and industry alliances. He is a member of the IEEE Computer Society Standards Activities Board and is an active leader in IEEE, the IEEE Computer Society, and the IEEE Standards Association. He is a partner in YAS Broadband Friends, LLC, and holds several patents. He serves on the boards of directors and technology advisory boards of companies developing emerging communications technology along with being a board member of the University of New Hampshire’s Broadband Center of Excellence. Mr. Nikolech has held technical leadership positions at large and small networking and technology companies (e.g., Broadband Access Systems, Racal-Datacom, Appleks, Motorola, and Analogic). In 1978-1979, he received a B.S. in electrical engineering, a B.S. in biology, and an M.S. in biomedical engineering from Polytechnic University in Brooklyn, NY, USA (now the NYU Tandon School of Engineering).