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International Network Generations Roadmap

2022 Edition

Deployment

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An IEEE 5G and Beyond Technology Roadmap

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ABSTRACT

Wireless technologies have become a fundamental part of our daily life in the 21st century. They connect us to each other and to rich sources of information. They give us the ability to make efficient use of our time, allow us to have remote control over other technologies in our life, and make our lives better in innumerable ways. In order to function, our wireless devices need to connect to cellular sites that provide good coverage both outdoors and indoors. Thus, the success of any wireless network is predicated on successful deployment of equipment and systems. As the number of users grows, and the amount of data transferred increases, the laws of physics and information theory require placement of wireless sites closer to populated areas – creating new challenges for both carriers, site developers, and local governments. Wireless communications facilities cannot be deployed in a vacuum – communication across the product development chain and between private and public entities is critical to enabling practical solutions.

This chapter overviews stakeholder perspectives both public and private and begins to examine ways to ensure that all stakeholder perspectives are communicated and understood.

Key words:

Deployment, wireless communications facility, site, acquisition, carrier, municipal, local government, product management, marketing requirements, engineering requirements, regulatory, legislative, consensus, 4G, 5G, 6G

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INGR ROADMAP

1. INTRODUCTION

This chapter describes a high-level perspective and projection of opportunities and challenges in realizing the deployment of advanced wireless technologies on both private and public property. It overviews the social, economic, and political forces that may affect deployment, and suggests how stakeholder perspectives may be reconciled in the face of what is often a complex interaction.

NOTE: We recognize that this document does not address physical communication technologies such as twisted-pair copper lines, coaxial cables, or fiber optic lines. While these are of course important for the delivery of communication services, they are typically governed by existing laws, ordinances, and regulations. Indeed, most physical communications infrastructure is managed under franchise agreements and public utility regulation. In contrast, despite wireless communications facilities being a relatively new entrant to the mix of communications solutions, the technology transition away from wired towards wireless is evidenced by several trends in consumer behavior. Accordingly, this chapter will not address wired communications infrastructure, except in cases where it supplies connectivity to wireless communications infrastructure.

NOTE: This working group roadmap does not endorse any particular solution, company, political perspective, or research effort.

1.1. 2022 Edition Update

During 2021, the focus of wireless cellular deployment was primarily in conversion of existing 4G sites to support 5G Non-Standalone (NSA) service using Dynamic Spectrum Sharing. There were also several deployments using the millimeter-wave bands, and the launch of 5G fixed broadband service in several metropolitan areas. Augmenting the 4G network with 5G resources helped support increased usage of wireless networks as people continued to work-from-home and school-from-home in response to the ongoing SARS-CoV-2 pandemic.

As we begin 2022, the focus of wireless cellular deployment is focused on deployment in new spectrum bands; T-Mobile in the 600 MHz “low-band” reclaimed from broadcast television service and the 2.5 GHz bands they acquired from Sprint, and Verizon/AT&T in 3.7 GHz “mid-band” reclaimed from TV receive-only service. Low-band deployments will extend basic coverage across wide areas, and mid-band deployments will add high-performance coverage to suburban and urban areas.

2. WORKING GROUP VISION

The Deployment Working Group (DWG) is a forum for information sharing and discussion among stakeholders, technical and otherwise, in the emerging 5G and beyond economy.

Deployment of wireless communications facilities occurs in a variety of settings, and are sited on private property, public property, or tribal land. Heterogeneous Networks, which are *small cell* and *distributed antenna system* (DAS) sites interoperating with wide-area *macro towers* and *monopoles*, are often sited on utility and lighting poles owned by private utilities, public utilities, public agencies, schools, or tribal or municipal governments. Applications for attachment of these wireless communication facilities are processed and issued by a variety of government agencies and jurisdictional authorities. This has created an environment where application, permitting processes, codes and ordinances, and aesthetics of wireless communication facilities are inconsistent across jurisdictions.

The popularity of wireless communications for voice, text messaging—and especially high-speed data—combined with increasing scarcity of electromagnetic spectrum resources requires the wireless industry to deploy more sites and shift their deployment focus away from the high-power and wide area coverage macro tower and monopole sites used for 1G, 2G, 3G, and early 4G networks towards low-power small cells and DAS on utility and lighting poles—this deployment strategy is called "densification" because it adds capacity and performance to an existing network by focusing resources on locations where subscribers live, work, or congregate. Densification means wireless communication facilities are necessarily sited closer to human populations, which creates challenges very different from the zoning and aesthetic review challenges that confronted the industry during the era of macro tower and monopole construction. At the same time, the increase in investment for densification in urban areas comes at the cost of rural wireless coverage where macro coverage is often still lacking. Spectrum auctions are organized, and auction bids are submitted, based on population clusters, which has an unintended consequence in that rural areas—with their lower population densities—are overlooked in favor of dense urban clusters rich with potential customers.

Because wireless communication facilities are deployed by for-profit wireless carriers or communications real estate developers, the interactions between carriers/developers and local governments or agencies are sometimes characterized by conflict, because each party is answerable to different stakeholders, and may have divergent goals or needs.

In particular, because densified wireless communication facilities are sited close to residential neighborhoods and population centers, particular attention must be paid to auditory and visual aesthetics, and to reassuring residents and the public that the technologies are safe.

Local governments traditionally have not hired staff skilled in managing wireless communications facilities. Technology is, in general, a relatively new function in local governments and agencies, and wireless communications is not yet an area where they have developed processes and expertise. Prior to 2015, wireless communication facilities were typically large macro or monopole towers sited on private or government-owned land properties, and a local government or agency might handle one or two within a five-year period. Starting in 2015, as the wireless industry began transitioning towards densification and deployment in the public rights-of-way as a means to serve exponentially-increasingly user demand, local governments and agencies had to shift ownership of application permitting and oversight to their public works departments, and the number of applications changed from single digits every few years to several dozen at a time.

The goal of the DWG is to help inform the wireless industry about the tactical challenges of deployment in and around public right of way—including private properties adjacent to the public right of way affected by local government zoning/planning, and to highlight the particular needs and perspectives of local governments and municipal agencies where applications for deployment of wireless communications facilities will be reviewed and permitted.

Additionally, the DWG seeks to help local governments and agencies charged with reviewing and permitting wireless communication facilities understand the technical requirements and underlying engineering or physics of wireless technologies.

2.1. Scope of Working Group Effort

The DWG serves as a bidirectional conduit for public sector, governmental, and tribal stakeholders to communicate their goals and concerns to the wireless industry vendors who are specifying and designing future network products, equipment, and systems. It is hoped that by doing this, the products the industry ultimately produces are better suited to meet the requirements and needs of local government and municipal agency review, permitting, and appeal processes.

The DWG also serves as a conduit for the wireless industry to communicate their goals and concerns to the public sector, governmental, and tribal stakeholders who are responsible for enforcing federal, state, and local laws and regulations, and who are responsible for managing public property. It is hoped that by doing this, the public sector, governmental, and tribal stakeholders will build application review and aesthetic requirements that align with practical engineering and physics principles of wireless communication facilities. It is also hoped that the public sector, governmental, and tribal stakeholders will understand the importance of wireless technology to modern society and the economy, and allocate appropriate resources to the application review and permitting process.

Topics covered by the DWG roadmap are:

- Local government factors and perspectives affecting deployment
- Legislative, regulatory, and engineering factors affecting deployment
- Public/community/resident factors and perspectives affecting deployment
- Technology challenges and trends affecting deployment

Wireless communication facility deployments occur primarily on three general property categories: privately-owned, publicly-owned, or tribal. Some types of property such as transit stations, water towers, etc. will fall into one of the three categories depending on local variance; e.g., utility poles might be owned by a government entity, a private utility, a tribal government, or by a joint-powers authority.

In most cases, the factors and perspectives affecting deployment are common to all wireless technologies, and in those cases we make no distinction between 4G, 5G, Wi-Fi, etc. In some cases, there are differences between wireless technologies that affect deployment, and these are noted as such.

Government regulation and legislation affect the deployment landscape for wireless technologies. As is often the case, the tensions over local control with state/regional, national, tribal, or international interests are dynamic and evolving. For this roadmap, we note and discuss the effects of regulation and legislation, but the DWG roadmap deliberately avoids making policy recommendations.

It is important to consider that 5G is the first cellular generation designed to support more than just handsets and smartphones, and as such it will be harder for the public to consider the risk vs. reward tradeoffs. 5G is a macro definition that expands the cellular data network to support use cases for machine-to-machine communications, fixed broadband, high-accuracy timing and positioning, etc. These use cases are often new to the general population, and that lack of familiarity likely fuels an aggressive opposition to 5G that is unsupported by science and socio-economics. While a city-wide Internet of Things network for traffic monitoring and control might in fact provide value to residents and citizens, and no doubt they will benefit from positive outcomes enabled by the network, unlike their smartphones and devices, they will have no direct interaction with the technology, and may resist deployment due to that lack of familiarity.

Fostering innovation that leverages the 5G and beyond network is key to its success. 3G networks enabled mobile email and mobile personal digital assistants, 4G enabled smartphones—both were revolutionary innovations unforeseen prior to network definition and construction. As of 2021, there are no revolutionary innovations that make use of 5G and beyond networks—these will be conceived, developed, and realized by future entrepreneurs. Previous generations of wireless telecommunications have proved that "If you build it, they will come." It remains to be seen if this maxim will hold true for 5G and beyond.

2.2. Linkages and Stakeholders

The primary stakeholders for the Deployment Roadmap are wireless carriers, local governments and agencies, state/regional governments and agencies, federal governments and agencies, regulatory agencies and commissions, telecommunication site owners, site build contractors, wireless equipment vendors throughout the supply chain, local businesses, tourists, and ultimately residents where the deployment of wireless facilities occurs. Secondary stakeholders include industry organizations, standards bodies, non-profits, and not-for-profits operating in the telecommunications sector.

The work of other INGR groups ultimately influences the success or failure of deployment efforts. These groups, and the reasons they are related to deployment, include the following:

- Massive MIMO: The size, weight, and power consumption of Massive MIMO antennas will determine their success in deployment. Utility or light poles used for deployment have limited weight-bearing capability, wind-loading and seismic restrictions, and the age of the pole also plays a factor. Poles located in historic and/or other sensitive areas present aesthetic challenges. Local governments and agencies often have design standards that require internal wiring—and the conduits that carry wiring must also support lighting, sensors, meters, etc. Municipal aesthetic standards may not allow mounting of bulky antenna boxes on poles.
- Edge Computing: Due to the placement of existing infrastructure, limited widths in the rights-of-way, and various safety concerns; municipal codes and ordinances often assert maximum enclosure sizes for telecommunications equipment. If a given allowed enclosure does not allow for additional equipment, deployment of edge computing cannot occur without changes to the enclosure or modification of the governing codes and ordinances. The size of the leasehold area for the telecommunications equipment can also determine if Edge Computing is viable.
- Optics: The availability of electric power and data backhaul are critical for wireless communication facility deployment. By far, the current preferred backhaul technology is fiber optic cabling.
- Connecting the Unconnected: 5G and beyond technologies have the potential to improve coverage in unserved and underserved areas, because it can serve more concurrent user sessions than 4G, and makes more efficient use of limited spectrum resources.
- Hardware: Densification of wireless networks places site equipment in closer proximity to human populations, which presents challenges for product managers across the hardware development ecosystem. For example, many local governments have noise ordinances for telecommunications and utility equipment, so if a semiconductor intended for use in a 5G radio has low power efficiency, the radio designer may be forced to use an enclosure fan, and the noise from that fan might exceed local noise ordinances. Knowledge of factors affecting deployment

informs market and engineering requirements; leads to better product management, and ultimately makes deployment less challenging.

- Security: Today's wireless networks use core servers, but 5G and beyond will allow the siting of edge computing nodes in the field, collocated with wireless radio equipment. Edge computing thus potentially creates increased opportunities for physical and logical security attacks. 5G network architects anticipate that large numbers of edge computing nodes will be required, and ever-increasing numbers of small cells will be required as well—especially at the millimeter wave frequencies where path loss limits coverage to under 100 meters. Ongoing pressures to reduce the cost of edge devices and the cost of installing them could also create opportunities for more security attacks. Mitigating this threat will require network and physical site hardening; stronger equipment enclosures, and enhanced security monitoring, creating additional requirements for enclosures—and possibly requiring adjusted municipal codes and ordinances. Mitigating this threat will also require two-way authentication of network devices and edge-computing devices, in addition to the now-standard authentication of subscriber devices. (In other words, just as subscriber devices must prove their authenticity to network devices, network devices must also prove their authenticity to subscriber devices if communications are to be trusted, reliable, and private.)
- Testbeds: Many local governments, eager to reap the political benefits of being seen as an early adopter of 5G and beyond technology, will want to be designated as testbeds.

The INGR DWG anticipates extensive dialog and interaction with other industry groups and standards bodies, as well as organizations that serve the interests of local/regional/state governments. These may include, but are not limited to, the following:

- Standards Bodies
    - American National Standards Institute (ANSI)
    - Telecommunications Industry Association (TIA)
- Industry Groups
    - Cellular Telephony Industry Association (CTIA)
    - GSM Association (GSMA)
    - Small Cell Forum (SCF)
    - Wireless Industry Association (WIA)
- Government Organizations and Associations
    - National League of Cities (NLoC)
    - State-based government groups; League of California Cities, etc.
    - American Public Works Association (APWA)
    - City/County Association of Governments (C/CAG)
    - National Conference of Mayors (NCM)

Figure 1. Components of a Macro Cellular Site
(Photo/Edits by David Witkowski)

Figure 2. Components of a Small Cellular Site

(Photo/Edits by David Witkowski)

In the experience of the DWG co-chairs, education of all stakeholders (carriers, site owners/operators, contractors, local governments, and agency leaders) is critical to successful deployment of wireless communications facilities.

Local governments and agencies are often very skilled at managing the traditional roles of government, but they lack experience and expertise in telecommunications—especially small cell 4G and 5G. At the same time budget constraints, regulatory limits on site lease rates and permit application costs, and competition for talent limit their ability to resolve this issue via hiring.

Deployment of wireless communication facilities entails several stakeholders:

- Vendors of electronic design and automation (EDA) software and systems
- Designers and manufacturers of semiconductors and subassemblies
- Designers and manufacturers of wireless radios, antennas, and supportive equipment
- Telecommunication site owners and developers, including Real Estate Investment Trusts (REITs) and design/build subcontractors
- Companies that use wireless networks as a platform for the delivery of services and systems
- Wireless carriers operating in licensed and unlicensed spectrum
- Regulatory bodies (both technical and non-technical) at the federal and state levels, and local commissions
- Legislative bodies at the federal, state, and local levels
- Elected officials

In developing this chapter, the DWG considered several interrelated questions around the deployment of wireless technology deployment:

- Stakeholder Considerations
    - Who are the stakeholders that are (or should be) involved in wireless deployments?
    - What are the needs and goals (current and future) of those stakeholders?
    - Related to the value of wireless technology, what are the current perspectives of those stakeholders?
- Knowledge Gaps
    - What is the current state of stakeholder knowledge related to wireless communication facilities and their socio-economic values?
    - What are the gaps in stakeholder knowledge that must be addressed and rectified?
    - How will those knowledge gaps be addressed?
    - What are the consequences if the knowledge gaps are not addressed?

3. Today's Landscape

3.1. Current State of Technology and Research

The first three generations (1G/2G/3G) of cellular technologies were deployed on towers and monopoles away from population centers, in a similar fashion to (and often collocated with) public safety and commercial two-way radio transmitters, paging systems, and mobile telephone service/improved mobile telephone service (MTS/IMTS) systems that pre-dated cellular telephony—these types of sites are referred to as "macro sites" because they cover large areas with radii of a few kilometers—sometimes more in rural areas. While conflicts with residents, preservationist/naturalist groups, and governments/agencies over macro sites were not unknown, in general they were located away from population centers and as such any conflicts were usually over view line aesthetics, potential fire risks, access roads, and possible impacts to native species and biodiversity preservation efforts. 4G technologies originally followed a macro site deployment model, but user demand grew exponentially after introduction of the smartphone—creating negative effects on network performance.

To improve 4G network performance, and to make more efficient use of limited spectrum allocations, the wireless industry turned to densification via Heterogeneous Networks (HetNets), combining macro sites with Distributed Antenna Systems (DAS) and small cell facilities—low power sites that augment coverage and improve performance for clusters of users and population centers. Unfortunately, this densification effort created several new issues:

- Siting near population centers led to resident fears about health effects from electromagnetic radiation, property valuations, and aesthetics.
- The number of applications for wireless facilities in the public rights of way increased dramatically, adding workload for municipal staff—often without an offset of new revenue to hire additional staff or provide technical training to educate existing staff.
- The question of who should bear the cost for application processing for cellular siting on public infrastructure is unresolved. Municipal governments have an obligation to manage public assets in a competitively neutral manner, and to assert rights to control those assets on behalf of residents. Some regulatory bodies at the state or federal level have asserted that harmonization of costs and rates is in the interest of providing coverage to the general population, however, these blanket assertions may not take into account variable local conditions.
- The issue of aesthetics (both visual and auditory) becomes important during the application process, especially during public review and planning/zoning hearings.
- The IEEE, ICNIRP, FCC, EPA, ETSI, United Nations ITU and WHO (refer to the acronym table for clarification), numerous researchers, and numerous industry groups have invested great effort over the past five decades to research health effects from electromagnetic fields (EMFs) and to establish science-based standards for safe EMF exposure. Based on that international body of science and evidence, regulatory authorities in countries around the world have set guidelines for EMF exposure, and required wireless carriers and network operators to certify compliance. In the U.S., the FCC has asserted authority over RF exposure safety standards, and Congress and the courts have maintained that the FCC's authority preempts state and local governments from denying deployment of wireless communication facilities based on concerns about the safety of RF exposure. And yet despite five decades of research showing no adverse health effects from RF exposure within the defined limits, some elected officials at the local, state, and national level, and some organizations who purport to be operating in the public interest, such as anti-vaccination groups, continue to question the safety of even low levels of RF exposure.

As of this writing, an internet search for "5G safety" will return several pages of opposition ranging from somewhat reasonable perspectives urging caution, to unsupportable pseudoscience and even outright conspiracy theories. During the 2020 pandemic, several conspiracy theories emerged; claims that 5G caused the SAR-COV-2, or that 5G increased the severity of COVID-19 infections, and even that 5G would be used to activate and control "chips" that would be injected into the population as part of a SARS-COV-2 vaccination program. These conspiracy theories were amplified by actors, musicians, and social media influencers—leading to vandalism and destruction of cellular towers in several countries. It is not an exaggeration to say that groups opposed to deployment of wireless technologies—especially those in opposition to cellular deployments—are winning the public debate by being vastly more adept in publishing material in support of their positions, and driving Internet search engines towards their perspective.

We note that 5G is not the first generation of cellular technology to generate concerns. Historically, the launch of each generation of cellular has met with opposition. Notably, this is true for non-cellular technologies. Wi-Fi was (and still is) feared by some people. “Smart Meters”, which operate at very low power levels and duty cycles, met with fierce opposition from some residents. Electric blankets, microwave ovens, fluorescent lighting, and LED lighting were all feared at one point. In the late 1800’s people feared electricity itself, and by extension incandescent lighting. We should expect that people will be afraid of 6G, 7G, etc. We need to recognize that people tend to fear new technologies, which is a very human thing to do — but ultimately science should prevail in public thought and policy-making.

It is incumbent on the wireless carriers and mobile network operators that expectations about 5G and beyond technologies be set properly. That 5G technologies will deploy gradually, as both new infrastructure and upgrades to existing 3G/4G sites, and as “non-standalone” configurations where 5G resources augment existing 4G networks, adds a new dimension to the deployment process that may be confusing to the general public. If the real world performance of 5G does not live up to marketing hype, the public may become more resistant to deployments in their communities.

Local governments and agencies operate on limited budgets and must prioritize application of limited resources—every dollar spent is a dollar taken away from another project. As stated previously, until around 2015 cellular macro sites were handled as a planning and zoning matter. The transition to heterogeneous networks has created an additional burden for handling wireless communication facilities application and permitting onto public utilities and public works departments. These organizations were neither funded nor trained to deal with the complexities of wireless communications facilities with large numbers of sites. Also, the processes and ordinances developed for cellular macro siting were not appropriate for heterogeneous networks in the public rights-of-way. Local governments are experienced in managing streets, sidewalks, parks, traffic and street lights, sewers—they will need to become experienced in managing wireless telecommunications applications and permitting as communications is increasingly a basic requirement of daily life in the 21st century. The question is how will they do this with limited financial resources and expertise?

3.2. Drivers and Technology Targets

The success or failure of 5G and beyond technologies will hinge in part on the ability of carriers, telecommunications real estate providers, and network operators to deploy wireless communication facilities close to user populations. In order to do this, several things are necessary:

- Education of government staff, elected officials, appointed officials, tribal leaders, commissioners, etc. about the social, economic, and technological impacts of wireless technologies
- Training of government staff, elected officials, appointed officials, tribal leaders, commissioners, etc. on how to efficiently handle applications for wireless facility deployments in their communities
- Design of wireless communications facility equipment by the industry that meets or exceeds the safety and aesthetic standards set forth by regulatory agencies and local governments and

agencies responsible for managing and maintaining the public rights-of-way on behalf of residents and citizens

- Clarity about the purpose of the 5G and beyond network, and communication about the value proposition of potential applications, beyond the current handset and tablet use cases for 3G/4G
- Entrepreneurship that makes innovative use of the 5G and beyond network, to create the "killer app" that will realize the potential of the technology in the same way that mobile PDAs made use of 3G networks, and smartphones made use of 4G networks

4. Future State (2032)

4.1. Vision of Future Technology

Given that 5G networks in millimeter wave bands will require 10 times more small cell sites than 4G networks, we should expect that the issues outlined in Current State (Section 2, above) will only be exacerbated—indeed we are already seeing growing resistance from community groups over wireless facility deployments, based largely on concerns amplified by urban legends and pseudoscientific fears about 5G health concerns.

Expertise from a wide variety of resources must be brought to bear on the deployment challenge. For example, engagement with the medical research community to review studies and publish expert opinions will help bring sanity to the current state of evidentiary self-selection. Despite more than 50 years of existing research, some politicians have called on the wireless industry to fund additional research into electromagnetic health effects. We believe any studies funded by industry will be tainted by perceived (or real) bias, and thus we believe that funding for health research must come from the government itself in order to remain above reproach.

The potential value of the IEEE as a voice of reason in the deployment debate cannot be understated. IEEE C95.1 forms the basis for current regulatory guidelines including the aforementioned U.S. Federal Communications Commission safety guidelines. The IEEE, while known to the general public primarily via association with Wi-Fi and the 802.11 family of standards, is large enough and independent enough to drive fact-based public discussion and education around the complex challenge of deployment.

Conflicts between federal agencies have the potential to impact 5G deployment. For example; in the latter months of 2021, the Federal Aviation Administration (FAA) expressed concerns that 5G sites in the C-band (3.70 – 3.98 GHz) might impact radar altimeters (aka "radalts") operating in the 4.20 – 4.40 GHz band, despite published evidence from the Federal Communications Commission (FCC) showing no impacts and U.S. airlines experiencing no adverse impacts when flying near international airports where C-band 5G is already in use. As of this writing, the FAA has cleared over 90% of commercial airframes for use near C-band 5G sites, and has stated that although some radalts are possibly susceptible to C-band 5G emissions, the radalt antennas (which point groundward and have strong attenuation of out-of-band signals) are not affected by C-band emissions. Moving beyond the conflict required deliberate and open cooperation between the FAA, airlines, the FCC, and wireless carriers.

Key to the success of this effort is continued partnership with industry groups, standards bodies, and government organizations. Dialog between the wireless industry, carriers, site owners, local governments, agencies, and residents is a proven formula for success, but it does not happen organically.

The question of local control versus federal control must be resolved. Courts and legislative bodies will need to nullify, modify, or uphold regulatory rulings—whatever happens, the uncertainty is damaging to planning and requires resolution. Federal agencies can and should engage in robust discussion and debate, but ultimately the decisions of expert agencies must be respected.

The deployment challenge will require creative thinking, partnership, and cooperation among all stakeholders. For example, to alleviate the lack of telecommunications expertise in local governments, the industry should consider a "talent partnership" model that would fund employees of carriers, wireless site owner/operator companies, and technology vendors to do a one-year working sabbatical with a local government or municipal agency. The government or agency would benefit from the added no-cost headcount, the industry employee would pass along knowledge in the process, and the employee would develop a first-hand understanding of municipal government operations and processes.

In a perfect world, presuming alignment between most or all stakeholders, we envision:

- Within three years:
    - IEEE has successfully engaged in publication of public-facing fact-based articles and materials addressing the deployment challenge.
    - After a review of the 2019 update to IEEE C95.1, the Federal Communications Commission reaffirmed their electromagnetic safety guidance in OET Bulletin 65, and closed their 2013 proceeding initiated to update electromagnetic safety standards. Likewise, the International Commission on Non-Ionizing Radiation Protection updated their guidance in light of the IEEE C95.1-2019 update. After some initial concern from opposition groups, these actions are now accepted by stakeholders, and any relevant legal challenges are resolved.
    - Conflicts between federal agencies regarding 5G are resolved by good science and a growing body of real-world evidence.
    - Stakeholder meetings between the wireless industry, governments, and standards bodies have developed an initial framework for dialog and interaction.
    - Wireless equipment vendors have adjusted their product roadmaps and offerings to meet the major concerns against deployment expressed by local governments, municipal agencies, and residents.
    - Local governments and municipal agencies are beginning, with the help of multiple agency partnerships and some industry-funded talent partnerships and educational efforts, to build up staff with telecommunications experience.
    - Courts and legislative bodies have debated and ruled on the issue of federal regulatory mandates versus local control, and stakeholders have arrived at agreeable terms for siting remuneration.
    - Common standards and best practices for processing applications are widely adopted and accepted by the majority (if not all) municipal governments and agencies.
- Within five years:
    - IEEE is considered a leading "go-to" source for the press and media reporting on the subject of wireless technologies and deployment challenges.

- Wireless equipment vendors are continuing to produce products that meet or exceed requirements outlined by government and public stakeholders for deployment.
- Local governments and municipal agencies are mostly staffed and trained to accept and review applications for 5G wireless communication facilities.

- Within ten years:
  - The success of the 5G deployment over the preceding decade has laid the foundation for future success as 6G and other technologies near standardization, and begin to displace 5G and earlier technologies.

5. NEEDS, CHALLENGES, AND ENABLERS AND POTENTIAL SOLUTIONS

5.1. Summary

Table 1. Overall Needs

Needs	*Description*
Need 1 : Education of Local Governments and Agencies	Local governments and agencies, at both the staff and elected levels, must become educated about the value of wireless communications technology in modern life, the science and medical evidence that supports rational analysis of the health effects of electromagnetic fields generated by wireless networks.
Need 2 : Education of the Public	The general public must be educated about the value of wireless communications technology in modern life, the science and medical evidence that supports rational analysis of the health effects of electromagnetic fields generated by wireless networks. Misinformation must be confronted and actively corrected.
Need 3 : Education of the Wireless Industry	The wireless industry must be educated about the constraints and limitations under which local governments and agencies must operate.
Need 4 : Education of the Semiconductor Industry	Semiconductors are foundational to wireless communications equipment and systems, and as such they must be designed with the end-user in mind. In particular, attention to the energy and thermal efficiency of semiconductors must be addressed, in order to ensure that wireless communications equipment does not require active cooling or oversized enclosures.

5.2. Education of Local Governments and Agencies

5.2.1. Challenges

Local governments and agencies are often resource-constrained, with little to no budget to hire and retain employees skilled in telecommunications. Elected officials are typically not engineers or technologists. Thus, local governments are simultaneously tasked with reviewing and processing often complex applications for wireless communication facilities, without the resources or understanding necessary to effectively manage the process, or to adequately respond to concerns about impacts from wireless communication facilities on private property or in the public rights-of-way.

5.3. Education of the Public

5.3.1. Challenges

The public are confronted with a wide variety of information sources, not all of which are authoritative. Social media channels enable the rapid spread of misinformation, further confusing the public as to what is correct versus incorrect. The complex nature of wireless technologies makes explaining the scientific and medical evidence for their relative safety challenging. The public also faces the challenge of understanding the inherent value of wireless technologies, especially new emerging technologies, in order to determine whether the perceived risks of unknown technologies are justified by the potential rewards.

5.4. Education of the Wireless Industry

5.4.1. Challenges

The wireless industry is composed of for-profit companies responsible to their shareholders and investors. The success or failure of projects to deploy wireless communication facilities hinges on successful interaction and cooperation with local governments and agencies, yet local governments and agencies have very different missions and motivations that may not align with the for-profit goals. Thus the wireless industry must seek to better understand those missions and motivations, and must in some cases temper their expectations for project scale and timelines.

5.5. Education of the Semiconductor Industry

5.5.1. Challenges

The semiconductor industry produces products that are critical to the success of the wireless industry and deployment of wireless communication facilities, but they are in many cases far-removed from the challenges faced by the wireless industry in executing successful deployments, and from the needs of local governments and agencies tasked with balancing deployment applications against the need to protect visual and auditory aesthetics in their jurisdictions. Inefficient semiconductors that produce excess heat require active cooling systems and/or large thermal mass enclosures—both of which are often unsuitable for deployment in the public rights-of-way.

6. Conclusions and Recommendations

6.1. Summary of Conclusions

Wireless communication is a vital resource in daily 21st century life, but deployment of wireless communication facilities in an increasingly complex world will not happen accidentally and cannot be left to chance. We must convene around this topic, understand the perspectives of all rational stakeholders, and define strategies that support deployments while respecting the needs and rights of stakeholders. Education is a key component of this process, as is the active countering of misinformation and pseudoscience. All tiers in the technology ecosystem, from semiconductors to equipment manufacturers and carriers/operators must be speaking to each other, as well as to the local governments and agencies tasked with reviewing and approving applications. This is an ongoing process that must continue as new technologies emerge — success will be a journey, not a destination.

7. Contributor Bios

David Witkowski is an author, advisor, and strategist who works at the intersection between local government and the telecommunication industry. He is a Fellow in the Radio Club of America, an IEEE Senior Member, the Founder & CEO of Oku Solutions LLC, and is the Executive Director of Civic Technologies Initiatives at Joint Venture Silicon Valley. After serving in the U.S. Coast Guard and earning his B.Sc. in Electrical Engineering from the University of California, Davis, he held leadership roles for companies ranging from Fortune 500 multi-nationals to early-stage startups. He serves as Co-Chair of the Deployment Working Group at IEEE Future Networks, Co-Chair of the GCTC Wireless SuperCluster at NIST, as a member of the Connected Communities Forum at the Wireless Broadband Alliance, and as an Expert Advisor to the California Emerging Technology Fund.

Mr. Witkowski is the author of "Bridging the Gap : 21st Century Wireless Telecommunications" (Joint Venture Silicon Valley - 1st Ed.: 2016, 2nd Ed.: 2019) and "Economic Impacts to Residential Real Estate from Small Wireless Facilities" (Joint Venture Silicon Valley - 2021), co-editor of "Public Wi-Fi Blueprint" (GCTC @ NIST – 2017) and "The Municipal Internet of Things Blueprint" (GCTC @ NIST - 2019), co-author of "5G vs. Wi-Fi: Challenges for Economic, Spectrum, and Security Policy" (Journal of Information Policy - 2021), co-author of "Carrier & Public Wi-Fi" (Mobile Experts LLC - 2015), co-author of "Deployment - International Network Generations Roadmap" (IEEE - 2021), and co-author of "HayWired Scenario, Chapter S, Vol. 3 - Telecommunications and ICT" (U.S. Geological Survey - 2021).

Tim Page is losing in on 10 years in the wireless infrastructure industry with Crown Castle. Specific emphasis on retaining and extending tower ground leases, building replacement towers, and deployment. Contributing member of IEEE (Institute of Electrical and Electronics Engineers) via the Future Networks and International Network Generations Roadmap projects, with specific emphasis on wireless infrastructure deployment.

More than 20 years of land development, planning, civil engineering design and construction management experience in the Northern California region. Particular expertise concentrated in project management of existing facilities modifications and new construction of retail shopping centers.

8. ACRONYMS/ABBREVIATIONS

Term	Definition
2G	Second generation cellular.
3G	Third generation cellular.
4G	Fourth generation cellular, an ITU-R definition governed by the IMT-2010 standard.
4G Advanced	An update to 4G, governed by the IMT-Advanced standard.
5G	Fifth generation cellular, an ITU definition governed by the IMT-2020 standard.
3GPP	Third Generation Partnership Project, a standards body.
ANSI	American National Standards Institute, a standards body.
ARPU	Average Revenue per User, a measure of system revenue relative to the number of users – to be profitable, ARPU must be higher than the total costs of building and maintaining the network.
Backhaul	The connection used to link a cellular site to the carrier's core network.
Bit	A single unit of digital information.
Broadband	Data that transfers at minimum speeds of 25 Mbps download, 3 Mbps upload (Per the FCC's 2015 definition).
Byte	A block of 8 bits.
CBRS	Citizens Broadband Radio Service, a 3.5 GHz band communications standard for Small Cells, used in the USA.
Cellular	A wide-area mobile wireless technology consisting of many sites interoperating as a network, for the purposes of providing voice and data communications.
Churn	A rough metric of the rate at which subscribers change from one carrier to another.
Co-Location	The installation of wireless equipment and antennas for multiple technologies and/or competing carriers to a single tower or wireless facility.
CPUC	California Public Utilities Commission, oversees and regulates companies that provide utility services using the public right of way.
CTIA	A trade association representing the wireless communications industry in the United States.
DAS	Distributed Antenna System, can be indoor (typically just called DAS) or outdoor (usually called o-DAS).
Dark Fiber	Fiber optic cabling which is unused and reserved for future use.
dB	Decibel, a unitless ratio of gain or loss.
dBd	Decibels of antenna gain relative to a simple dipole antenna.
dBi	Decibels of antenna gain relative to a theoretical point-source antenna.
dBm	Decibels of power gain or loss relative to a milliwatt of RF energy.
EB	Exabyte, 1×10^{18} bytes.
EIRP	Equivalent Isotropically Radiated Power, the product of transmitter power and the antenna gain in a given direction relative to an isotropic antenna of a radio transmitter.
eMBB	Enhanced Mobile Broadband, a 5G use profile primarily focused on handsets and user devices.
EMF	Electromagnetic Fields, the combination of time-varying electric and magnetic forces.
ERP	Effective Radiated Power, an IEEE standardized definition of RF power, measures the combination of the power emitted by the transmitter and the ability of the antenna to direct that power in a given direction.
FCC	Federal Communications Commission.

FirstNet™	A nationwide network of LTE and 5G, reserved for use by public safety, first responders, governments, and critical infrastructure users.
FWA	Fixed Wireless Access, a use case of 5G providing broadband service to fixed locations.
GB	Gigabyte, $1x10^9$ bytes.
GDP	Gross Domestic Product, the monetary value of all finished goods and services made during a specific period.
GHz	Gigahertz, $1x10^9$ hertz.
Handoff	The process by which a wireless voice or data connection is seamlessly transitioned from one site to another.
HetNet	Heterogeneous Network, a system of dissimilar wireless technologies operating as a whole.
Hz	Hertz (cycles per second), a measure of signal frequency.
ICNIRP	International Commission on Non-Ionizing Radiation Protection.
IEEE	Institute of Electrical and Electronics Engineers, a standards body.
IoT	Internet of Things, the connection of stand-alone nodes, systems, and devices to the internet.
IP	Internet Protocol, the standard for data communications over the internet.
IT	Information technology.
ITU	International Telecommunications Union – the technology standardization and coordination arm of the United Nations.
Lattice Tower	A type of communications tower constructed from a lattice of metal sections – can be either guyed (GT) or self-supporting (SST).
Lit Fiber	Fiber optic cabling operated by a company that sells capacity on that fiber to multiple users.
LPWA	Low Power Wide Area, An Internet of Things communications technology that uses low power, low data rate communications for devices.
LTE	Long Term Evolution, the name for a 4G-compliant radio standard published by 3GPP.
LTE-A	LTE Advanced, a higher performance version of LTE.
LTE-LAA	LTE-License Assisted Access, a 3GPP-compliant LTE-U technology.
LTE-U	LTE-Unlicensed, a technology to carry LTE waveforms over the 5 GHz unlicensed spectrum bands.
Macro Site or Tower	A large tower (either guyed or freestanding) which supports communications equipment and antennas.
Mbps	Megabits, $1x10^6$ bits per second.
MBps	Megabytes, $1x10^6$ bytes per second.
MHz	Megahertz, $1x10^6$ hertz.
MIMO	Massive Multi-Input Multi-Output, an antenna architecture used to focus RF energy towards a receiver.
MMTC	Massive Machine-Type Communications, a 5G use profile.
Mobile Economy	The exchange of goods and services delivered to consumers by smartphone apps.
Monopole	A type of freestanding wireless tower.
MSO	Multiple System Operator, an operator of multiple cable or direct-broadcast satellite television systems.
mW	Milliwatt, one thousandth of a watt.
NFV	Network Functional Virtualization.
NGH	Next Generation Hotspot, a standard that allows Wi-Fi devices to use foreign networks without requiring a manual log in process.

NIH	National Institutes of Health, the primary agency of the United States government responsible for biomedical and public health research, an agency of the U.S. Department of Health and Human Services.
NTP	National Toxicology Program, a project within the NIH.
NR	New Radio, the name for a 5G-compliant radio standard published by 3GPP.
Offload	A network enhancement technique where parallel networks handle requests for large amounts of data (such as streaming video) – usually through a LTE-U, LAA, or Wi-Fi node.
OnGo	The trademarked name for CBRS, governed by the CBRS Alliance.
PAL	Priority Access License, a CBRS user tier.
PCS	Personal Communications Service, an FCC regulation created for early digital telephony and data services.
PWC	Price Waterhouse Coopers, a consulting firm.
RF	Radio Frequency.
Roaming	The automatic sharing of networks, used to provide subscribers with a larger number of available sites without requiring user intervention.
SAS	Spectrum Access System, a system that governs channel access and priority in CBRS.
SDN	Software Defined Networking.
Shot Clock	The period defined by regulation during which a local government or public agency must respond to an application for wireless facilities in the public rights of way.
Small Cell	A type of communications equipment that operates at lower power levels than a macro site. Small Cells typically cover areas from a single room up to several hundred meters in radius. They are attached to other structures such as building roof perimeters, streetlights, and utility poles.
Spectrum	The range of RF frequencies used by a wireless system.
TSN	Time Sensitive Networking, a 5G use profile.
uRLLC	Ultra-Reliable Low-Latency Communications, a 5G use profile.
VoLTE	Voice over LTE.
VoWiFi	Voice over Wi-Fi (sometimes referred to as “Wi-Fi calling”).
Watt	A measure of power, used to define RF power levels.
WHO	World Health Organization, an agency of the United Nations.
Wi-Fi	Wireless Fidelity, a trademark name for the IEEE 802.11 data communications standard.
Wireless	Telecommunications of voice or data using RF methods.

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