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Abstract	Abstract:-Within the wireless industry there is growing recognition of capacity and throughput challenges posed by the new regime of broadband user devices now joining cellular networks. The social and consumer trends unleashed by multimedia sessions using these devices is inducing new behaviors in wireless users and undoubtedly heightening strains on existing network capacity. This paper explores new architectural, protocol, and spectrum approaches that could increase network wireless capacity and the modularity that will be necessary to keep pace with future media-rich service demands. The author suggests the long term solution to the capacity and throughput limits of current cellular networks may be found in expanding the frequency range and bandwidth capacity of cellular network infrastructure to include millimeter wave spectrum up to and beyond 300GHz. The utilization of these frequencies by future wireless cellular networks will follow the emergence and availability of low-cost mass produced transceiver technologies optimized for millimeter and sun-millimeter frequencies. The availability of low cost high frequency radio transceivers will in turn drive the development of efficient beam steering methods that will be critical for a broad range of applications including extreme bandwidth nanocells. Small sized nanocells, operating in coordinated clusters, will be able to take advantage of evolving network topologies and the enormous spectrum resource offered by higher millimeter and sub-millimeter (THz) frequencies. These extreme frequencies will permit nanocells to efficiently deliver multi-Gigabit Ethernet-like throughputs to the wireless marketplace. The author examines the radio environment, network and technological considerations that must be resolved to exploit millimeter and terahertz frequencies for next-generation extreme-

	throughput wireless communications.
Purpose	This document is supporting material for both the authors slide presentation as well as reference material for the focus and activities of the 802.15 IG THz
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Evolution of Extreme Bandwidth Personal and Local Area Terahertz Wireless Networks

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Abstract:-Within the wireless industry there is growing recognition of capacity and throughput challenges posed by the new regime of broadband user devices now joining cellular networks. The social and consumer trends unleashed by multimedia sessions using these devices will undoubtedly heighten the strain over time. This paper explores new architectural, protocol, and spectrum approaches that could increase network wireless capacity modularly to keep pace with future media-rich service demands. The author recommends spectrum at near-THz frequencies to provide Gigabit Ethernet-like wireless throughputs, and examines the technological barriers that must be overcome to exploit them for next-generation extreme-throughput wireless communications networks.

1 Introduction

The electromagnetic spectrum historically used for radio services has satisfied the world's wireless communication needs for a century. But today, devices like the iPhone™ represent a new vision of portable personal information access that has opened a universe of user options and services that were only dimly imagined a few years ago. We are still coming to terms with and understanding the potential and usage implications of these remarkable devices.

As a result, there is a growing industry consensus that today's cellular networks may be approaching a "tipping point" due to mass use of "smart" portable devices, prompting a rush to dramatically increase capacity. The current tendency appears to focus on PHY technology enhancements such as 4G (4th Generation wireless) and MIMO (Multiple Input, Multiple Output intelligent antenna technology) as well as modest additional spectrum additions to enhance wireless network capacity and catch up with surging customer bandwidth demand. The author believes that the thrust to expand network capacity using more sophisticated PHY (network physical layer) signal processing with incremental frequency augmentation to satisfy increasing "personal bandwidth" demands may prove only a short term expedient rather than a sufficiently long term solution.

2 The Wireless Network Challenge

The unparalleled adoption and massive technological and infrastructure expansion of cellular telephony since the early nineteen-eighties has been explosive, to say the least. Once considered expensive and a status symbol for the elite, more than four billion people out of the 6.8 billion world population[1] now use cell phones[2]. Remarkably 61% of this growth is in developing countries according to Trends in Telecommunication Reform: the Road to NGN – *ITU 8th Edition, Sept. 2007* [1]. Furthermore, fully one billion people worldwide are Internet users with a large portion of this population accessing the Web through their cell phones.

In the U.S., according to a Cellular Telecommunications Industries Association[3] 2004 study [2] there were 171 million wireless subscribers. Several years ago cellular subscriptions eclipsed wired connections and the annual wireless growth rate climbed to over 13% compared to a wireline decline of 6%. In addition, the CTIA report states the number of U.S. households reporting cell phones as their primary phone was 17.5% in 2008 and will exceed 37% by 2012. In short, the U.S., and indeed the world, is quickly becoming a wireless information community.

Beyond this massive growth in cellular infrastructure, the behavior of mobile phone customers has also dramatically changed in recent years. According to Business Week Online, *Sept, 22, 2008* [3], [4] the number of Americans with "unlimited" cellular data plans rose 58% from the year before. The number of Americans accessing media–rich data and social networking sites via mobile phones rose 93% in the 12 months through to June 2008. The average owner of an iPhone now transacts three times the amount of data than did early iPhone users. From a business perspective, this recent shift in consumer bandwidth surge has doubled data revenues to $27 Billion between 2005 and 2008. More cellular users, more bandwidth consumed, more profit for the cellular industry [5] - the sky truly seems the limit for this industry!

But as is often the case, with great success also comes great challenges. The Business Week Online article goes on to state that cellular service providers are "struggling to keep up", and "didn't quite anticipate how quickly data demand would skyrocket". As a result, "carriers are charging more" and "are placing limits on data usage" to conserve network bandwidth and spectrum. This industry pushback is clearly a

[1] U.S. Census Bureau
[2] ITU Press Release, September 2008
[3] Now known as "CTIA - The Wireless Association"

reaction to recognition of the bandwidth and capacity limits of existing cellular systems.

To achieve longer-term balance between escalating user demand, network cost and spectrum usage, it will be necessary to consider a combination of evolutionary and revolutionary approaches. The evolutionary component must push dense spectrum reuse much further, enabled by a leap to very small cell sizes, richer backhaul, and flatter, less hierarchical network architecture. The revolutionary component is to open under-utilized millimeter wave and near-terahertz spectrum using a "cloud-based" spectrum manager to orchestrate access to "extreme" broadband wireless on demand for a variety of cellular and WLAN air interfaces in selected high-teledensity environments.

3 Leaving Large Cell Architectures Behind

Radio communication, like DSL before it, has increasingly become a "Shannon" business that is forcing network designers to confront the "law of diminishing returns" as they attempt to balance spectrum, link budget and battery power in portable devices. Moreover, the cost to develop and deploy a new cellular generation is significant, and so it is important to evolve existing systems when possible. New PHY technologies can help the evolution, but large cell link throughputs assisted by modern signal processing are already approaching the limits defined by Shannon.

Acknowledging the observation, the cellular industry long ago embarked on the road of "cell splitting" to boost the capacity of an initial "coverage first" layout. Microcells, when used with richer backhaul and reduced transmit power levels, effectively demonstrate that backfilling the equivalent coverage area of a large macrocell yields higher capacity by more intensely reusing channel frequencies where capacity demands are high. Cell splitting has been proceeding in an orderly fashion until now, driven mostly by growth of voice traffic volumes. However, the opening of cellular networks to the Internet has put network design onto a new growth curve: broadband data. As in the wired network, broadband data volume is growing substantially faster than conventional voice telephony. The author believes that cell sizes will have to shrink precipitously to cope with this data influx, leading to much smaller cells and exponentially more of them. The consequence is disassembly of the current hierarchical cellular architectural model in favor of a flatter, more distributed-intelligence architecture in order to maintain scalability. An example of this change in thinking is the "femtocell", a concept that has arisen from both cellular and wireless LAN parentage.

The femtocell [6] is the latest cellular technology being considered for indoor cells, and its service vision is similar to the throughput and coverage of current Wi-Fi systems. Femtocell base stations operate at low RF power (milliwatts compared to watts for a macro or microcell), typically illuminating interiors of home or enterprise buildings using an "underlay" philosophy with guidance from the macrocellular controller. Wi-Fi networks, by contrast use an Ethernet-like model and operate in license-free spectrum using a "flatter", more distributed network management architecture. Femtocells are currently undergoing tests, but one could argue that Wi-Fi has already proven the ability of small cells to deliver very much larger throughputs to users, though not yet designed for vehicular, wide-area mobility coverage.

Willingness of users to value such service is also apparent. The popularity of Wi-Fi has underwritten the penetration of "dual-mode" Wi-Fi enabled cell phones, and more so suggests a path toward accommodation of new services in separate spectrum, limited only by the frequency coverage of a device's transceiver. One might argue that Wi-Fi has been both a "nursery" for development of 4G architectures and a "safety valve" for 3G systems whose capacity might have been challenged by too many multimedia user sessions at once.

One could easily envision a new network enhancement that could provide throughputs perhaps 10-100 times larger than today's wireless LAN systems by using small cells, fiber backhaul, and higher frequency spectrum, with "tri-mode" devices.

4 Triple-Stack "Nanocellular" Architectures

To realize the above scenario the author proposes the creation of a third independent wireless transport stack in parallel with the existing cellular and Wi-Fi stacks. This new framework would provide bi-directional, high bandwidth connectivity between a portable device and a base station in spectrum not necessarily associated with either cellular or Wi-Fi networks. The existing cellular and Wi-Fi stack and spectrum would be used for slower real-time communication augmented by the third stack for "extreme" throughputs.

For convenience we could call this new physical layer a "superchannel" and the coverage areas "nanocells", which might be conceived as the next gradation smaller than microcells, serving as the basis of a "Neighborhood Area Network" or NAN. Fiber, FSOC and millimeter-wave backhauled nanocells could be added over time, with new nanocells deployed as supplementary sites to systematically backfill the local tri-mode microcell's coverage area and provide expanded superchannel footprint coverage as service demand and operator budgets dictate.

The nanocell's radio coverage area is envisioned to be small (sub-kilometer), and each nanocell would be designed to function as part of a nanocellular "cluster" centered within the existing microcell. The operating parameters of each nanocell would be adapted to optimize that nanocell's behavior with respect to other members of the cell cluster. The nanocells would cooperatively select available frequencies to minimize co-channel interference, while supporting dense frequency reuse and more rapid handoffs between nanocells.

Access to the superchannel may be facilitated by a "frequency router" in the user device that detects what air interfaces are available, what user traffic is being communicated, and which air interface would be most appropriate. An example of such a router is the IEEE 802.21 Media Independent Handover standard, which utilizes a companion "cloud-based" coordinator to orchestrate handoffs cooperatively with the device. In such a scenario, one air interface stack is used to "bootstrap" transfers of traffic to another network with its own stack, Interestingly, such a frequency routing technique could allow an air interface to be constructed without an explicit control plane, consisting of only bearer channels which would be "scheduled" by a cloud-based "virtual media access control layer" or V-MAC".

5 Exploring the Need for Extreme Throughputs: Human Bandwidth Limits

The definition of "extreme" throughputs is relative. Typically, wireless LAN designs have used Ethernet speed families to predict what broadband capacity would be required for the next wireless "generation". However infrastructure mode wireless LANs are more like Ethernet hubs: they aggregate the throughputs of a group of users who are present in a coverage area, the types of services available and aggregated bandwidth throughput required to support these new services is growing rapidly. According to Michael Kassner in his TechRepublic web article [7], the current cell tower aggregated bandwidth, as a shared medium, runs between 3-4 T1's (6Mbps), and upgrading to 3G provides 9Mbps, such marginal bandwidth enhancements will not likely support the surge of wireless broadband users and media rich services. New cellular technologies such as WiMAX and LTE could offer theoretically 75Mbps and 300Mbps respectively, which will provide some relief to the bandwidth bottleneck, but with the increasing number of iPhone users and other media rich devices, for how long?

New types of services such as VoIP (Voice over Internet Protocol) and HDR (High Definition Radio), are being proposed to use cellular and Wi-Fi frequencies. VoIP and HDR utilization of this already scarce spectrum resource will add significant load to the existing wireless infrastructure, an increase that would not likely be sustainable even with proposed bandwidth enhancements provided by 4G and LTE technologies. How the cellular networks and service providers respond to these new market challenges and in respect to their historic dominance of this spectrum remains to be seen.

Frank McCoy of RadioWorld [8], further addressed the impact HDR will have on existing cellular infrastructure in his recent blog titled "The Problem Isn't Demand, Its Bandwidth". In his article McCoy notes that HDR would provide 48 Kbps per customer. If this aggregated bandwidth is delivered via cellular frequencies for a listening audience of 2000, the

aggregated HDR bandwidth would be 96 Mbps. The HDR allotted bandwidth alone would exceed the capacity of next generation 4G cellular technology. For a sense of comparison, McCoy notes that an audience size for a successful Chicago radio station can be 25,000 listeners.

A white paper by Moray Rumney from Agilent Technologies [9], reviews the various options and capabilities of the diverse family of 4G and LTE technologies, and which technologies are likely to be capable of supporting proposed wireless broadband services such as bundled IPTV, Ethernet and voice. According to Rumney, personal wireless device data rates would need to be in the range of 1Gbps per device to support these types of wireless broadband services. Thus the total cell site capacity and backhaul requirement would then have too be scaled to the number of expected real time peak users within that cell area coverage and the time of day.

Rumney's article suggests the channel size for a LTE based wireless Gigabit service, assuming a spectrum efficiency >10 b/s/Hz/cell, would be in the order of 100 MHz. Unfortunately 100 MHz of contiguous spectrum is not easy to envision in today's congested radio spectrum. The WRC -07 World Radio Conference - 2007 was able to identified only two bands at 2.6GHz and 3.5GHz that could support this band of spectrum. It may be possible in the future with advanced multi-transceivers to aggregate non-contiguous frequencies to achieve a full 100 MHz channel, but such technologies are far from realization.

6 How much personal bandwidth is enough?

Recent studies indicate the human eye transfers information to the brain at roughly Ethernet rates of 10Mbps/eye [10]. It might seem that real time data rates for devices delivering audio and video through the ears and eyes to the brain, might not have to greatly exceed this throughput per person. At first glance, the conjecture would seem to predict an eventual plateau in personal throughput growth. However, two factors are surfacing to keep the average throughput/person growing: Personal agent technologies and an "instant gratification" mentality for bulk content access are emerging as the next user interface layer for both wired and wireless network access.

First, fueled by seemingly relentless Moore's Law progress in mobile device processor speed and memory, we are likely to experience the rise of computing "surrogates" to filter the deluge of real-time information made available to us via the Internet, sensor clouds, and social networking into the tens-of-megabits the human interface can accommodate in real time. The throughput required for "awareness" of the surrogates, may exceed human bandwidth by several orders of magnitude, judging by the expansion rate of new information and the extent to which remote sensing will become pervasive. Hence the bottleneck for the emergence of truly pervasive computing and information exchange may not be in the portable device or server infrastructure computing resource, but rather in the air transport of this data between the handheld device and the network.

An interesting slide presentation by Intel Research, University of Michigan and Carnegie Mellon University [11], examines efficient use of network surrogates and infrastructure for caching and transferring of file data to a client. The model uses 802.11b wireless networks operating at 11 Mbps for its analysis. What can be easily derived from this paper is that the wireless interface is clearly the bottleneck in the data transfer flow process, this is especially apparent when transferring large files such as movies, which at these wireless bandwidths can take hours to download.

Second, again fueled by abundant, inexpensive memory and broadband networks, is the realization that large files with content such as entertainment can be treated as "containerized" deliveries provided sufficient transport bandwidth is available. Files can be time-shifted and downloaded quickly and at a time convenient to the user. This pattern is already becoming commonplace as broadband connections multiply: Users are choosing multimedia content for later use and then downloading it while a connection is available rather than using it in "real time". Movie downloads are usually too large to be downloaded quickly, if we consider the contents of a 25 GB Blu-ray disc, it requires just over two and a quarter hours to transfer this data at 802.11g speeds of 25 Mbps.

But if one were to use extreme throughput wireless connections that are capable of transferring data at gigabit and multi-gigabit burst rates, and that can deliver data hundreds of times faster than 802.11g speeds, then new possibilities would open for the user experience. Armed with the conviction that personal bandwidth will keep growing, how could future "extreme" throughput wireless technologies offering gigabit, even multi-gigabit channels, and be accommodated within the confines of the existing radio spectrum? Are there sufficient bandwidth blocks available to support multiple gigabit channels within a cellular like distribution model?

7 Spectrum Availability for Extreme Data Delivery Wireless Networks

Accepting that wireless is now a Shannon business we realize that personal throughput translates to utilization of a piece of spectrum (licensed or unlicensed) over a specific coverage area and for a limited period of time for each user. To support such locally adaptive utilization of spectrum, throughput and physical space, cooperative clusters of small sized cells would need to preferably utilize large channel sizes rather than higher transmit power.

Higher frequencies are usually less accessible technologically, and so may offer larger untapped contiguous spectrum resources as well as promise of potentially large channels. Conversely the attraction for high frequencies is blunted by higher propagation losses and other adverse behaviors related to wavelength. For example, higher radio frequencies usually suffer from decreased atmospheric penetration, and greater scattering losses. These propagation concerns can to some extent be mitigated by shorter links such as would be the case with nanocellular architectures.

Selection of bands at higher frequencies for extreme data delivery will vary from country to country and from location to location within a country, and coordinated use of this spectrum clearly be desirable for the realization of extreme data delivery clustered nanocells worldwide. In the U.S. for example, a number of higher frequency "Fixed and Mobility" bands are available up to the FCC-regulation boundary of 300 GHz, but these are not always aligned with worldwide allocations.

If one were to consider applications utilizing higher frequencies outside the traditional FCC spectrum domain, for example, a terahertz data transfer system operating around 300 GHz (the low end of the THz band) [12], one must understand the behavior of E/M waves with such short wavelengths. For example, at frequencies beyond 300 GHz significant molecular absorption "holes" produce increased atmospheric attenuation and scattering effects. These propagation losses may be further influenced by contributions from surrounding materials and structures, including their reflective and absorptive properties, all of which need to be taken into account when designing wireless systems at these frequencies.

Members of ITU - US Working Party 7C [13], have released a draft paper in August of 2009 with analysis of the 0.3-3 THz spectrum in preparation for upcoming ITU/WRC spectrum allocation considerations for both scientific and active (commercial) services. The paper focuses primarily on the 1-3 THz band, but details the atmospheric absorption and attenuation properties of molecular oxygen and water between 300 GHz (0.3 THz) and 1 THz. The paper details the attenuation losses by frequency and various altitudes ranging from sea level to 3000 meters. The paper's analysis indicates losses were the greatest at sea level due to increased levels of oxygen and water vapor. Frequencies between 0.3-1 THz generally had the lowest losses ranging from approximately 7 dB/km at 0.3 THz to over 250 dB/km at 1 THz. This 700 GHz span also includes a number of molecular absorption (attenuation) features that exceed 10,000 dB/km. Frequencies beyond 1 THz show periodic absorption features with extinctions well beyond 100,000 dB/km. Even the lower loss bands in this 1-3 THz spectrum span have attenuations ranging from 250 dB/Km to 2000 dB/km and are unlikely to have useful terrestrial communication (near sea level) applications offering any significant distance.

The 0.3-1 THz spectrum span has a number of discrete bands that may be comparatively considered "low loss" and may be applicable to wireless communication applications such as short range terrestrial, indoor and potentially outdoor THz communications. The excessive molecular losses between 1-3 THz render this 2000 GHz span less favorable for longer distance communication applications, but lower loss segments in this region may still find application in close-range machine-to-machine links for example; multi-processor back planes. The maximum contiguous spectrum width within the low loss 0.3-1 THz band varies in from 25 GHz near the frequency of 300GHz to over a 100GHz worth of spectrum near 1 THz. These discrete "low loss" THz bands represent an enormous untapped spectrum resource for extreme bandwidth wireless communications. Additionally the 0.3-1 THz low loss bands are largely outside the THz bands of scientific interest which tend to dominate the 1-3 THz band.

Beyond molecular absorption, and atmospheric propagation of THz frequencies, researchers at the Terahertz Communications Lab, Institut für Nachrichtentechnik, Technische Universität, Braunschweig, Germany [14], have investigated specular reflective and scattering properties of terahertz frequencies and their interaction with common building materials. This work is especially applicable to in-building, in-room omni-directional terahertz wireless applications and may provide insights into larger scale outdoor deployments. A materials surface texture and composition also produce differing interactions with THz frequencies, materials such as crystalline dielectrics, glass and polymers have the highest THz transparency, metals the highest reflectivity and hydrated materials the greatest absorption, building materials designed to enhance or suppress these effects may become important for indoor and outdoor terrestrial THz wireless networks.

8 THz Transceiver/Antenna Architectures

Perhaps the most critical consideration for diffuse THz applications is related to the THz antenna itself. Omni-directional antennas are usually designed to function effectively when they are a fraction of a wavelength. As wavelength becomes smaller, the antenna's aperture, (the area over which it collects or launches an electromagnetic wave), is correspondingly reduced. Conventional microwave cellular radios have antennas that are on the order of inches in length. But as wavelengths get smaller still, and especially in the higher frequency domains of millimeter and near-THz frequencies, antennas can shrink to literally microscopic proportions. For example a typical omni-directional quarter wave 300 GHz antenna would measure only 250 microns (1/100 of an inch), in length. The proportion of radio energy intercepted and collected by so small an antenna dramatically reduces link "reach", making nanocellular links tenuous. Is it reasonable to contemplate use of these frequencies for extreme throughput networks?

There are a number of well-documented means of overcoming the link budget problem. The more common are:

- Use better signal processing and/or coded-modulation methods for closer Shannon approach
- Transmit fewer bits per second, increasing the energy/symbol and eventually "spreading"
- Increase the transmit power until an acceptable link margin is obtained
- Collect more of the transmitted power by using a larger collector – in other words increase the antenna gain and aperture

Of the four basic options above, only the last is likely to prove valuable for THz use. Signal processing and advanced coding have already come within a few dB of Shannon. Since the vision for the application is extreme throughput, reducing the transmission rate is counter-productive. Increasing transmitted power is itself a law of diminishing returns, particularly at THz frequencies due to device limitations and battery constraints. However antenna gain grows by the square of the collecting aperture (in the case of a dish collector), providing an efficient, low-noise means to increase received signal. But increasing the antenna size-to-wavelength ratio (aperture enhancement) increases the transmission beam directivity and thus decreases its areal coverage. At the receiver, the antenna "sees" a smaller field of view through which to receive the intended transmission, which can further complicate link alignment. If some form of active beam steering and tracking could be implemented at both ends of the THz link, such high gain antennas could be used to advantage in nanocells providing both high throughput and acceptable transmission distances.

MIMO antennas are seeing increasing application for beam steering at lower GHz frequencies but at a price of increased system complexity and signal processing requirements. However, a bright spot on the horizon is provided by the ability to integrate a transceiver and steered antenna into a hybrid package that can be inexpensively duplicated. For example the small wavelength of terahertz frequencies means that they can be reflected by small “mirrors”, much like visible light. Thus, combining a terahertz radio with a suitably-scaled Micro-Electro-Mechanical System (MEMS) micro-mirror array [15] whose “addressable” surface array of reflective micro-mirrors can be dynamically configured to steer a THz beam in much the same fashion as a computer projector can create an image on a screen far from a light source. Other emerging technologies such as spatial light modulators, dielectric lenses and metamaterials [16], [17] show much promise for manipulating THz waves as well.

In the more distant future, one can conceive of a future fiber-connected terahertz “tennis ball” base station composed of many transceiver/antenna modules disposed in a circular or semi-spherical array that could emulate isotropic coverage using a “spatial router” and directed high frequency beams.

9 Closing the Link

Practical THz wireless systems for public space and outdoor mobility applications will require extending the link reach up to and beyond 100 meters. Recent experiments by Battelle Memorial Institute [18], using frequencies between 92 to 140 GHz and highly directional beams have demonstrated 10 Gbps throughput, beyond one kilometer. Scaling to THz frequencies, extreme throughput application environments such as in-room, in-building and “floodlighted” nanocellular pedestrian plaza environments would appear within reach.

Clearly, today’s THz applications such as imaging, remote sensing, medical and security scanning, materials analysis, drug and food safety, to name a few, will lead the way, especially in a world marketplace demanding increased focus on environmental, security, medical, food and drug safety. Practical THz communications for nanocell extreme throughput applications will have to await the development of mass produced, low cost, high speed semiconductor devices. Special purpose devices are being developed today, but with projected device geometry and high frequency material advances, the availability of mainstream THz radio “building blocks” for communication system uses should be available within 5 years. Recent announcements from companies such as T-Ray Science Inc [19], and a broad suite of industrial and university materials research groups [20], [21] show a rapid maturation of silicon THz antennas and associated transceiver architectures that are helping to move THz device technology ever closer to the promise of low cost, mass-produced radios.

10 Standards Activities Beyond 300 GHz

In the US historically-defined FCC “radio” boundaries end at 300 GHz, the start of terahertz frequencies. THz frequencies span between 300 GHz and end at deep infrared light (10 THz). Terahertz frequencies are gaining attention for a variety of commercial applications [22], [23] including communications. The relatively low loss frequency region between 300 GHz and 1000 GHz (one terahertz) represents 700 GHz of unlicensed spectral resource, though not all of it is usable due to molecular attenuation. The low loss bands within this 700 GHz span of spectrum offer an unparalleled expanse of bandwidth beyond what is available in today’s radio spectrum. Organizations such as ITU Working Group 1A, 7C7D [13] and the IEEE 802.15 & 802.18 [24] organizations as well as numerous international government regulatory organizations are actively working toward spectrum coordination and device standards in this spectral region. Interestingly, the International Amateur Radio Union (IARU) [25] has expressed strong interest as well, underwriting the vision to use it as a communication medium.

11 Last Thoughts On An Emerging Technology

These are still early days for THz technologies and applications. There is enormous untapped bandwidth within the relatively low-loss frequency segments lying between 300 GHz and 1000 GHz. Even with simple modulation methods and a low spectrum efficiency of one bit per Hertz, a 300 GHz channel bandwidth could theoretically yield three 100 Gbps channels of potential throughput in an intense-reuse nanocell environment. One can only guess at what changes in the sociology of information-sharing would arise from availability of such wireless throughput.

Just 30 years ago cellular “microwave mobile” seemed daunting, but today its use is taken for granted as a “talk anywhere” enabler. Just 15 years ago, cellular data and Wi-Fi were a curiosity, and now it is difficult to live without them. It is likely that within a decade from today terahertz extreme throughput systems will be equally commonplace, and each of us will be experiencing a new wealth of multimedia “born digital” content the world will have produced by then at our fingertips. It is indeed an exciting time to be privileged to design such a future.

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A Very Short List of Research Institutions Working On Terahertz Technologies And Applications Referenced In This Paper.

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Boston University, College of Engineering , Boston, Massachusetts, USA.
Commonwealth Scientific and Industrial Research Organization, ICT, Centre Marsfield, NSW, Australia.
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