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Ultra-wideband radio technology: overview and future research

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Abstract

The emergence of commercial wireless devices based on ultra-wideband radio technology (UWB-RT) is widely awaited and anticipated. UWB-RT is not only applicable to communications, imaging and ranging, it also promises to alleviate the problem of increasingly scarce spectrum resources while enabling new wireless applications and business opportunities. These prospects have caught the early attention of the technology-providing wireless industry and, more recently, that of the radio regulatory authorities. Moreover, the technical challenges and problems to be solved when conceiving and deploying UWB radio systems have spurred a growing interest within the wireless research community. This paper discusses the key characteristics and capabilities of UWB-RT and indicates where one expects to exploit them in applications. A brief overview of the current status of UWB-RT is provided and directions for future research are discussed. It is proposed to explore and develop this new technology in the context of 'wireless systems beyond 3G' and within a forum of sufficient international breadth to facilitate regulatory and standardization frameworks with global support.

Keywords: Ultra-wideband radio technology; Wireless systems; Data communication; UWB; UWB-RT

1. Introduction

The emerging modern version of ultra-wideband radio technology (UWB-RT) is built on a long history of technological advancements based on the underlying principles and characteristics of wideband radio signals; a comprehensive account of the historical developments and principles of UWB-RT can be found in references [1,2].[1] Given the potential of UWB-RT for covert communication and ranging systems as well as the lack of appropriate regulatory guidelines regarding spectrum usage, the development and use of systems based on UWB-RT have thus far been mainly the privilege of US military and government agencies. However, the recent initiative taken by the Federal Communications Commission (FCC) in the US to regulate the legal use of UWB radio devices have not only induced growing commercialization activities but also similar regulatory and research efforts in other geographies, notably in Europe [3–5].[2] For example, CEPT study groups are currently investigating how to regulate the commercial use of UWB radio devices within the spectrum range 1–40 GHz such that they can coexist with other radio services. However, neither the FCC nor the CEPT will ultimately provide the functional standards for UWB radio systems. This important task can only be tackled by the pertinent industry and appropriate standard bodies *after* the necessary regulatory framework has been laid and based on—preferably broadly supported—market needs and technical requirements.

The recent regulatory efforts and the significant technological advances made by several US-based pioneering developers of UWB-RT have spurred a growing interest within the wireless industry as well as within academic and

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[1] Lists of patents, papers and books related to UWB-RT at http://www.aetherwire.com/CDROM/Welcome.html.

[2] FCC/Part 15 permits operation of certain radio frequency devices without a license or need for frequency coordination; it also seeks to ensure a low probability that unlicensed devices will cause harmful interference to other spectrum users. Part 15.109 rules subject unintentional radiators (devices not intentionally transmitting a telecommunication signal) to a set of limits. For example, for frequencies >960 MHz the electrical field strength at 3 m distance from the source is not to exceed 500 μV/m (rms) when measured in a 1 MHz bandwidth. Specific limits for UWB devices are currently being prepared and on February 14, 2002, the FCC announced a *First Report and Order* to permit operation of certain types of UWB devices (http://www.fcc.gov/Bureaus/Engineering_Technology/News_Releases/2002/nret0203.html).

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other research institutions. The mainly classified nature of the early development efforts and the lack of legal spectrum regulations and limits explain the fact that widespread commercial interest in UWB-RT emerges only now. In this respect, the deployment of UWB-RT appears to follow a process similar to that observed during the commercialization of classical spread-spectrum communication systems [6].[3] Thus, given the present status of UWB-RT it appears appropriate to call for the inclusion of UWB-RT on the agenda of any forum contemplating the future of wireless systems, particularly those considering 'wireless systems beyond 3G'. We consider the latter notion to include (infrastructure-based) wide area cellular systems as well as local (ad hoc) networks for specific environments, e.g. self-organized network topologies and supporting systems capable of accessing cellular networks. A suitable podium for a comprehensive treatment of the technical issues associated with designing these next-generation systems is provided by the recently established *Wireless World Research Forum* (WWRF).[4] The WWRF aims to identify and promote research areas as well as technical and societal trends for mobile and wireless systems for the 'wireless world' that could become operational within a decade's time. The WWRF's list of proposed research tasks covers the multiple technical and operational aspects of future wireless systems, including the exploration of systems based on UWB-RT [7]. Although the technological basis of UWB-RT is apparently well understood and developed today, it is generally recognized that efficient realization and widespread commercial deployment and application of this new technology still hinges on several significant regulatory and technical challenges. These problems must be resolved before the very promising benefits of UWB-RT can possibly be consumed in practice. Thus, it appears both timely and sensible to attempt this by dealing with the corresponding regulatory and technical issues as well as standardization questions on a global scale.

Proponents of UWB-RT promise a broad array of new or improved (short-range) wireless devices and radio services that could provide enormous progress in the areas of public safety as well as for home and business applications.[5] It has been proposed that the FCC's Part 15 rules be amended such that the imposed power limits (maximal electrical field strength at a defined distance) are also applicable to intentional emissions from an UWB radio device [3].[2] It is claimed that, ideally, UWB devices could operate over the entire spectrum, including the bands reserved for other radio services without degrading their quality of operation. Although this assertion has been maintained by only certain proponents, the very question concerning the degree to which UWB devices can potentially cause harmful interference in the receivers of other radio services—notably the Global Positioning System (GPS)—has become the primary focus of regulatory procedures [8]. The resolution of these and other interference issues (e.g. cumulative impact of many UWB radio sources) require complex technical investigations and assessments; in addition, it is equally challenging to reconcile the various competing business interests with legitimate security concerns. For the purpose of this paper, we shall assume that the regulatory issues will eventually be resolved—preferably on a global scale.

The FCC has proposed a definition of UWB radio signals similar to that of the OSD/DARPA UWB radar review panel [3], i.e. that the fractional bandwidth—the ratio between the signal's bandwidth and center frequency—be greater than 0.25 (25%) or the signal occupy at least 1.5 GHz of the spectrum. The bandwidth is measured at the upper and lower cutoff points (−10 dB), f_H and f_L, respectively, and the center frequency, f_C, is defined as the average of these cutoff points, i.e. $f_C = (f_H + f_L)/2$. It is an open issue whether this definition should be applied only to UWB devices emitting pulsed signals of low duty cycle, where the bandwidth is inversely related to the width of the pulses. Clearly, other technical approaches can be employed to produce UWB radio signals, and it will be important to include these alternative methods in any future investigations of UWB-RT [9,10]. However, for the sake of brevity and objectivity, this paper focuses on UWB signals as characterized earlier and in Section 2, where potential applications are discussed. Section 3 gives a brief overview of the status of UWB-RT and indicates directions of possible future research, emphasizing the desirability of a regulatory and standardization framework with global support; conclusions are drawn in Section 4.

2. Key characteristics and applications of UWB-RT

This paper deals with UWB devices that transmit sequences of information carrying pulses of very short duration (e.g. 0.1–2 ns). These pulses are widely spaced such that the waveform's duty cycle is up to several orders less than unity (e.g. 1/10–1/1000). There are two principal methods to generate pulsed UWB signals. With the first method, the pulses are emitted as so-called baseband pulses, which in their purest form require spectra starting at very

[3] Further notice of inquiry and notice of proposed rulemaking (in the Matter of Authorization of Spread Spectrum and Other Wideband Emissions not presently provided for in the FCC Rules and Regulations), Docket No. 81-413, Federal Communications Commission, Release-Number: FCC 84-169, May 21, 1984; Adopted April 26, 1984.

[4] Wireless World Research Forum (WWRF) at http://www.wireless-world-research.org.

[5] Partial list of companies and organizations actively developing or promoting UWB-RT (alphabetical order). (a) Aetherwire and Location, Inc. (http://www.aetherwire.com): localizers; (b) Lawrence Livermore National Laboratory (http://www.llnl.gov): micro-power radar; (c) Multispectral Solutions, Inc. (http://www.multispectral.com): communication, radar, location; (d) Pulse~LINK, Inc. (http://www.pulse-link.net): wireless home networking; (e) Time Domain, Corp. (http://www.time-domain.com): communication, radar, location; (f) UWB Working Group (UWBWG;http://www.uwb.org): industry consortium; (g) XtremeSpectrum, Inc. (http://www.xtremespectrum.com): communication.

low frequency (nearly DC; e.g. (e) in footnote 5). The second method emits envelope-shaped 'pulses' in the form of several sinusoidal cycles (e.g. (c) in footnote 5). In systems that use the first approach, control of the signal's center frequency, f_C, and large emission bandwidth, $f_H - f_L$, is intimately coupled to the actual shape of the single pulse emitted from the antenna. The second approach offers a more independent adjustment of the signal's center frequency and—typically somewhat smaller—bandwidth. Furthermore, whereas the antenna is generally a more important spectral-shaping element in a system based on the first approach, the higher frequencies used by the second method tend to reduce the signal's ability to penetrate materials. In any case, independent of the method of signal generation, the following are some of the benefits and characteristics claimed for practical systems based on UWB-RT [3]:[5]

- *Extremely low power spectral density (PSD)*. Average power levels in the order of millionths of a Watt (μW) and excessive signal bandwidth yield power spectral densities in the order of several tens of nW/MHz.
- *Spectrum reuse*. Potential reuse of scarce spectrum resources by overlaying UWB emissions of extremely low power spectral densities on already assigned spectral bands.
- *Robust performance under multipath conditions*. The short pulses potentially allow differentially delayed multipath components to be distinguished at the receiver with the benefit that a reduced fading margin may be applied in a system's link budget analysis.
- *Multiuser communication*. The application of sequence-coded access methods to pulsed and inherently low-duty-cycle UWB signals could enable very densely populated multiuser systems with high immunity to interference.
- *High-resolution position location and tracking or radar sensing*. The large signal bandwidth yields a distance resolution between communicating devices or a radar-sensing accuracy within a few centimeters.

The inherently good receiver robustness in environments subject to multipath propagation and the fact that pulsed wideband signals are ideal for ranging applications enable one to conceive mobile short-range radio devices for the indoor environment that support (high-performance) digital data transmission as well as precise location determination and tracking. Therefore, it appears realistic to envisage certain future short-range wireless devices featuring scalable data communication combined with precise location tracking of mobile terminals. Achieving location awareness in ad hoc networks as required in Ref. [11] could be greatly facilitated by the availability of wireless devices offering precise location-tracking functions that support efficient multihop routing mechanisms. The ultimate benefits that UWB-RT could bring to ad hoc networking stem from the ability to couple location tracking with (high-performance) data transmission. As pulse-based UWB devices typically operate with a single transmitted pulse waveform in all modes, they offer a high degree of flexibility in terms of data rate selection and transmission range. The physical (PHY) and medium access control (MAC) layers of UWB radio devices are thus particularly suited for implementations based on software-defined radio principles. Changes in data rate and/or transmission range can be made, for example, by simply changing the transmitter's (average) pulse repetition frequency (PRF), possibly in combination with adjusting the number of information bits carried by a single pulse. This inherent flexibility of UWB radio devices is illustrated in Fig. 1, which shows results computed for an ideal free-space channel and a receiver that is subject only to additive white Gaussian noise. The figure compares UWB systems using antipodal signaling (APS) combined with pulse position modulation (PPM) with direct-sequence spread-spectrum (DSSS) systems using binary phase shift keying (BPSK). Clearly, to achieve the same data rate, BPSK-DSSS tends to require chip rates that are significantly higher than the PRF of a corresponding APS/PPM UWB system.[6]

UWB-RT potentially enables implementation of wireless platforms that support a variety of operating modes including data transmission, precision positioning and tracking, radar sensing or even a combination thereof. Thus, a wide range of novel wireless applications become possible, such as:

- Wireless personal area networks (WPANs) and wireless local area networks (WLANs) with integrated position location and tracking capabilities,
- multiuser ad hoc (self-organized) networking with location-aware routing support,
- high-rate wireless home networking (multimedia access and distribution; wireless connection of displays),
- alternate high-rate access into cellular network infrastructure ('hot spot' scenario),
- personnel and asset tracking (RF tagging), particularly in indoor environments,
- public safety applications, including motion detection in disaster situations,
- collision avoidance and proximity sensors for motor vehicles.

Expected key applications for UWB radio devices are data communication and position location and tracking, particularly in the areas of short-range systems (WPAN, WLAN) and ad hoc networking. The home and single-office/small business (SOHO) environments will presumably become primary target markets for systems that support link

[6] Details on the system model are given in Fig. 1, where the average power limit of 0.3 mW is the result of the assumed 4 GHz bandwidth and the FCC/Part 15.109 limit on the emissions of unintentional radiators. For frequencies >960 MHz this limit is 500 μV/m at 3 m distance, measured in a 1 MHz bandwidth (PSD at the source: −41.3 dBm/MHz; see Ref. [3] and footnote 2).

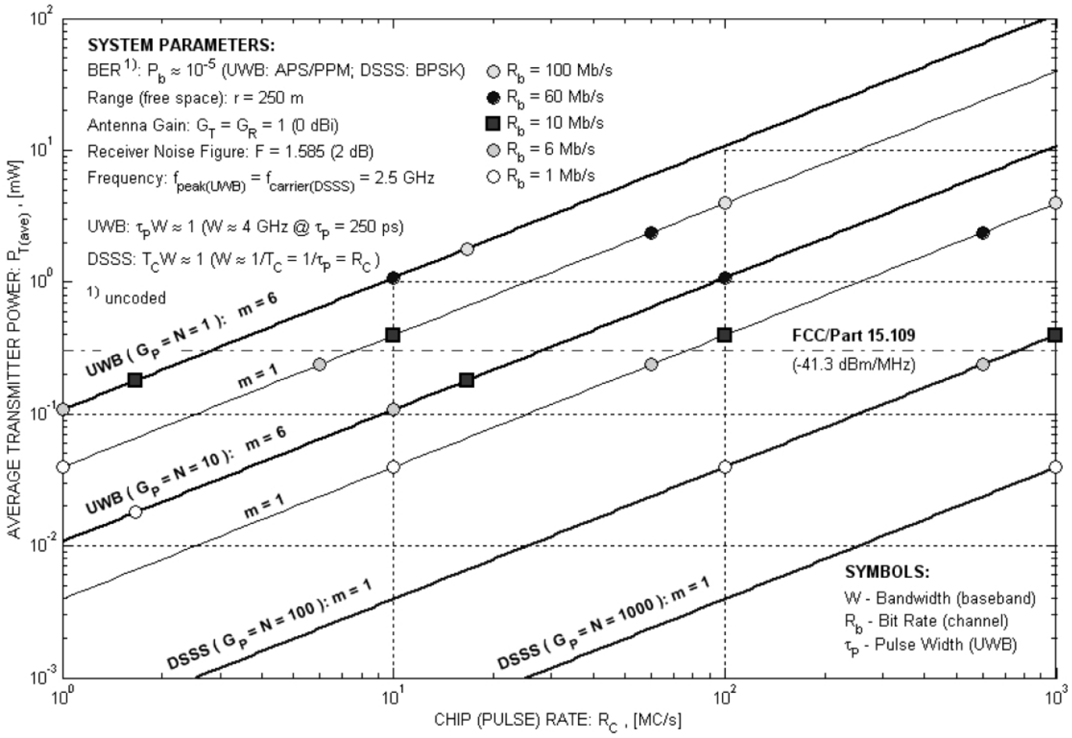

Fig. 1. Comparison of UWB and DSSS radio systems in terms of required average power vs. chip (pulse) rate to maintain a bit error rate (BER) of $P_b \approx 10^{-5}$ over the free-space channel (range $r = 250$ m) in the presence of additive white Gaussian noise. With M-ary modulation, $M = 2^m$, $m = 1, 2, 3, \ldots$, a pulse represents m bits, where the first bit encodes the polarity of the pulse. When $m \geq 2$, the remaining $m - 1$ bits define one of $L = M/2 = 2^{m-1}$ possible pulse positions within a chip interval (T_C). For $M = 2(L = 1)$ this hybrid modulation reduces to simple antipodal signaling (APS), whereas $M \geq 4$ ($L \geq 2$) results in a combination of APS and L-ary PPM (APS/PPM). The transmitter may repeat each pulse chip N times to achieve an (ideal) signal processing gain $G_P = N$ at the receiver. The bit rate over the channel is thus $R_b = m/T_S = (m/N)R_C$, $N \geq 1$, where R_C is the chip (pulse) rate, also called the PRF. There is a choice of the parameters m, N, and R_C to achieve some given data rate, R_b. For example, the four systems with parameters $N|m = 1|6, 1|1, 10|6$, and $10|1$ achieve $R_b = 10$ MB/s with $R_C = 10/6$, 10, 100/6, and 100 MC/s, respectively. Also shown are the results for binary phase-shift keyed (BPSK), direct-sequence spread spectrum (DSSS) systems with processing gains $G_P = N = 100$ (20 dB) and 1000 (30 dB), respectively. BPSK-DSSS systems are modeled by letting the pulse width be equal to the chip duration ($\tau_P = T_C$), setting the carrier frequency $f_{carrier(DSSS)} = f_{peak(UWB)}$, and assuming a spreading sequence of length N. Note that the BPSK-DSSS system with 20 dB processing gain ($N = 100$) requires a chip rate of 1 GC/s (!) to achieve a data rate of 10 MB/s.

distances of between 10 and 100 m. UWB systems covering much larger distances will mainly be reserved for exempt systems operated by military and government entities. For example, field tests of long-range UWB surface wave transceivers designed for the US Navy for non-line-of-sight video transmission over up to 60 nautical miles have been reported ((c) in footnote 5).

3. Current state of UWB-RT and future research directions

The US-based developers of UWB-RT have already achieved a rather advanced level in the design of PHY functions and, to a somewhat lesser degree, the MAC and higher-layer functions required to support the application scenarios described earlier.[5] In fact, it must be acknowledged that a few pioneering individuals and companies have collectively generated an impressive amount of intellectual property and complete concept or prototype systems that have proved to a reasonable degree the practical feasibility and benefits of UWB-RT [1,2].[1,5] However, a large gap exists between the current level of the base technology and the ultimately desirable state of widely available and highly integrated, cost/power efficient, standardized systems and applications, e.g. for integration into cell phones, personal digital assistants, laptops, and other mobile devices. A major task will be to achieve user-friendly coexistence *and* cooperation (e.g. handover) between existing and new systems alike, the WWRF is striving to provide an appropriate podium particularly in this area.[4]

3.1. System level issues

Short-range wireless systems based on narrow-band carrier modulation are often inadequate or incapable of providing sufficiently accurate information about a mobile terminal's location to support location-aware applications or routing; on the other hand, there is a growing need for these capabilities [11–14]. Fig. 2 is a rather speculative view of how devices based on UWB-RT can potentially outperform conventional radio devices both in achievable spatial capacity—measured in terms of aggregate data rate per unit area or (Kb/s)/m^2 [15]—and location precision.

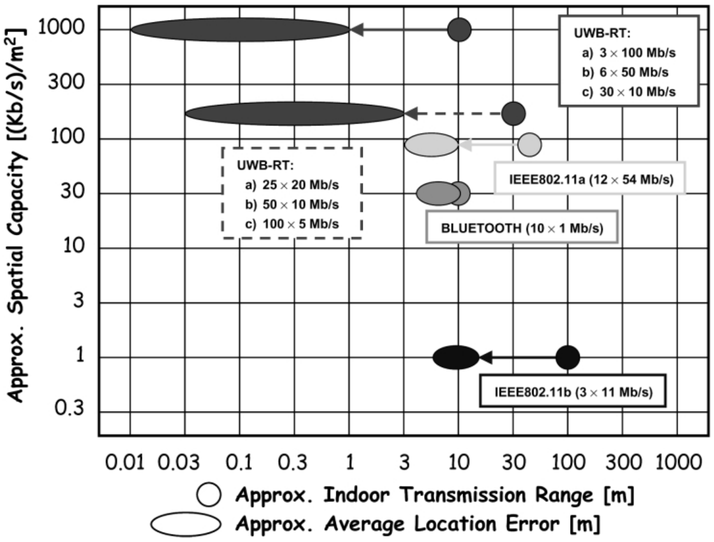

Fig. 2. A speculative comparison of UWB radio devices and conventional short-range wireless systems in terms of achievable spatial capacity, measured as the maximal aggregate data rate of N active devices per unit area (Kb/s)/m^2, maximal transmission range and average location error [12–14]. The notation 'IEEE802.11b (3 × 11 Mb/s)' means that three ($N = 3$) IEEE802.11b devices communicate simultaneously with three different access points, each at a data rate of 11 Mb/s over a distance of 100 m. Although rarely possible in practice, it is assumed that the specified maximal ranges and data rates are achieved simultaneously by all devices. Each of the various options for UWB-RT assumes that N active devices transmit at the indicated data rate by using some multiple access scheme (e.g. $N = 6$, data rate: 50 Mb/s, range: 10 m, [15]).

Whereas 'spatial capacity' can be a sensible metric to compare different systems, it should be noted that this measure is relatively sensitive to changes in the assumed coverage area, e.g. the spatial capacity quadruples when the coverage radius is halved. Thus, it remains an objective of ongoing as well as future research to determine the practical limits of achievable spatial capacity. Many open questions exist in the areas of system scalability (large number of UWB devices operating in a given area), mutual interference between similar and dissimilar devices, required and achievable level of quality of service (QoS), to name a few. Concerning localization, it will be necessary to determine the actually required level of accuracy for any given application and whether this level of quality can be maintained under varying channel and network load conditions. Direction estimation methods may be worth developing to enhance the basic distance measurement methods; ultimately, effective methods for two- and three-dimensional location tracking capabilities need to be developed. In ad hoc networking, the role and efficiency of the MAC function in a highly loaded network has to be assessed. Even if UWB-RT promises to deal well with the basic requirements of data communication and location tracking, practical and workable solutions that combine the benefits of both modes of operation have to be defined and evaluated. For example, aiming at high-rate data in combination with precision location capabilities may not always be the most sensible approach to pursue. Instead, it may be more practical to trade range for performance and thus support location-aware applications over much greater distances at a reduced location precision and in combination with low-rate data transmission.

3.2. Deployment and user scenarios

The choices for possible deployment and user scenarios when considering UWB systems for the enterprise and the consumer markets are abundant. It is thus imperative to consider carefully the all-important scenarios from which the key system requirements should be derived. In particular, the requirements relevant to the PHY and MAC layer functions must be clearly identified, e.g. link range, data rate, location precision, battery burden, level of adaptability to channel conditions, multiuser scalability, to name a few. Following this path, relevant research topics appear to be (i) definition of typical deployment environments (may be limited by regulatory restrictions), (ii) identification of realistic user and application scenarios where the use of UWB-RT appears to be a definite asset compared to conventional solutions (e.g. data mode combined with position location and tracking) and (iii) deduction of the technical PHY and MAC requirements that can enable the selected scenarios.

3.3. UWB radio channel and physical layer

A variety of modulation and sequence coding techniques as well as corresponding methods for signal detection and processing have been proposed or used in experimental versions of UWB radio devices.[5] Naturally, not all of these techniques are equally applicable under different practical operating conditions. It is necessary to assess the merits and drawbacks of the various known as well as new approaches by subjecting them to different usage scenarios and propagation environments. For example, it is not clear whether methods that average a large number of pulses to recover a bit of information will demonstrate sufficiently robust performance in situations of high relative velocity between transmitter and receiver platforms. In addition, although UWB systems feature a certain inherent robustness to multipath effects, they are not entirely immune to them. For example, in situations where there is an excessive ratio of link distance (d) to antenna height, the time difference between the line-of-sight and the reflected signal components can be substantially shorter than the duration of a pulse. This may result in signal losses according to the familiar $(d/d_0)^n$ attenuation model with $n \approx 4$, where d_0 is the reference distance. Extreme signal propagation situations can also be observed in indoor environments where the numerous multipath components associated with each transmitted pulse result in propagation delay profiles that last tens and even hundreds of nanoseconds [16]. The potential intersymbol interference caused by these not uncommon situations will severely limit the maximally achievable data rate of a system (small PRF) unless an effective method can be found that mitigates these effects.

A further aspect not entirely understood today relates to the deteriorating effects of in-band interference in UWB receivers that originate from other radio signals, be they in near- or far-field proximity. The problem of nearby interference is not only one of academic interest, considering that UWB devices might be integrated into mobile platforms that make simultaneous use of a variety of other radios. Thus, the very advantage that UWB devices emit an extremely low PSD—as a result of the excessive signal bandwidth—potentially yields increased susceptibility to noise and interference in the UWB receiver. Similar effects may occur in areas with a large concentration of active UWB devices; this raises questions concerning harmful compound effects of multipath propagation and cross-device interference phenomena. Further topics related to UWB channel and PHY issues offering research potential are:

- issues related to implementing the PHY of UWB radio devices, e.g.
  - — signal propagation, channel modeling and estimation,
  - — adaptive modulation methods and receiver architectures,
  - — dynamic rate adaptation in response to channel quality variations,
  - — achievable single-user data rate and aggregate data rate per unit area (spatial capacity),
  - — channel coding and error correction strategies,
- characteristics of UWB antennas (e.g. in proximity of objects and the human body),
- coexistence and integration of UWB radio devices with existing (short-range) wireless systems.

3.4. Packet routing in ad hoc networks and medium access control

A key application for UWB devices is expected to be in the area of ad hoc and self-organized wireless networks based on multiuser communication and multihop routing capabilities [11]. In this area, subjects that offer significant research potential are (i) definition of MAC functions to support ad hoc network architectures (e.g. location-based routing), (ii) influence of cooperative routing and associated protocols on the network load, (iii) investigation of multiple access schemes for UWB radio devices such as code division multiple access (CDMA) and (iv) methods to determine location information (e.g. MAC frame that supports applications using data communication and ranging).

3.5. Regulation and standardization of UWB-RT

Like any other wireless technology with a potential for widespread deployment, the eventual success of UWB-RT will depend greatly on the availability of suitable and timely PHY and MAC standards—in compliance with the rules imposed by regulatory authorities and backed by a representative part of the industry. Thus, broadly supported PHY and MAC standards will be a prerequisite for successful deployment. Fig. 3 illustrates that the regulatory framework and standardized PHY and MAC functions are also key building blocks for systems based on UWB-RT. Although one can argue over the degree to which the need for standardization depends on the intended application, the currently observed emergence of UWB-RT should be considered a unique opportunity to develop and standardize PHY and MAC functions suitable for short-range wireless systems that *combine* data communication and positioning capabilities. In fact, these combined capabilities are poorly supported by conventional narrow-band systems, which certain standardization efforts are already trying to improve [14, 17]. For example, the IEEE P802.15 ALT PHY Study

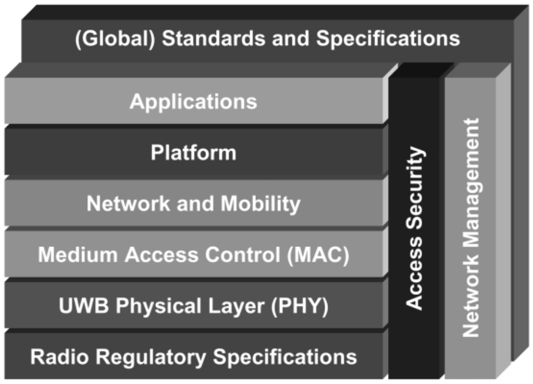

Fig. 3. The regulatory framework and (broadly supported) standardized PHY and MAC functions will also be the key building blocks of a system based on UWB-RT.

Group (SG3a) has recently issued a call for submission of *ALT-PHY-WPAN Application and Usage Scenarios* [17]. The group aims at a higher-speed PHY option for the IEEE 802.15.3 MAC to enable *imaging* and *multimedia* applications. Document [17] lists the following PHY requirements:

1. coexistence with all IEEE 802 wireless PHYs,
2. target data rate in excess of 100 MB/s for embeddable consumer applications,
3. robust multipath performance,
4. location awareness enabling applications such as range-dependent authentication,
5. anticipation of using additional unlicensed spectrum for high-rate WPANs to relieve possible spectrum congestion.

Although document [17] does not directly refer to UWB-RT, it is evident that the first four PHY requirements can nearly only be met *collectively* (!) if the PHY system design incorporates principles of UWB-RT, whereas the fifth requirement seems to anticipate future spectrum allocations for such systems. With this interpretation, the recently issued call in Ref. [17] appears well in line—albeit somewhat premature—with the earlier identified need for standardized PHY and MAC functions based on UWB-RT.

4. Conclusions

The key characteristics and potential application areas of UWB-RT were discussed, and a brief overview of the status of this emerging wireless technology was given, together with indications for future research. We have assumed that the regulatory issues governing spectral and power constraints (to be) imposed on UWB-RT *will* provide sufficient flexibility to allow the deployment of technically as well as commercially viable UWB radio systems. The desirability of—if not the need for—global regulation and standardization has been emphasized, recognizing that the necessary level of standardization may well depend on the intended application. Similar past standardization efforts for WLANs have clearly shown, however, that too expeditious and uncoordinated an introduction of standards bears the risk of creating (too) many standards, with the consequence that few enjoy sufficiently broad (global) support. To avoid some of these problems, we propose to discuss the standardization of UWB radio systems in a forum with sufficient opportunity to evaluate different options and which encourages a broad technical as well as user-centric debate—the WWRF could provide such a platform.[4] Commercial deployment of UWB-RT and its application is only on the verge of being explored and the development of devices towards form and power factors suitable for widespread integration in mobile platforms and appliances will remain a challenge for some time to come. This paper constitutes but an incomplete introduction to UWB-RT and provides a mere glimpse at the potential capabilities of this unconventional but promising wireless technology.

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