An Overview of the IEEE 802.15.4a Standard

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ABSTRACT

This article presents the IEEE 802.15.4a standard, the first international standard that specifies a wireless physical layer to enable precision ranging. As an amendment to the popular IEEE 802.15.4-2006, the IEEE 802.15.4a-2007 standard introduces new options for the physical layer in order to support higher data rates, extended range, improved robustness against interference, and mobility, while enabling new applications based on distance information of the devices in a low-rate wireless personal area network.

INTRODUCTION

There is little doubt that applications relying on sensory data collection and processing, which have driven the development of wireless sensor networks (WSNs) [1], are becoming increasingly popular due to the growing needs and emerging technologies in environmental monitoring and control [2]. The IEEE 802.15.4 standard [3] and the industrial consortium supporting it, the ZigBee alliance,[1] comprise an ideal technology to uphold the market demand for such applications, stimulating the development of numerous commercial products. The provision of low-cost and low-power wireless connectivity within short ranges of up to 20 m are some of the characteristics that made the standard particularly suited for sensor networking. Shortly after the release of the 802.15.4 standard, it was evident that the range of potential applications of a low-bit-rate standard could be significantly increased by the capability of measuring distance between devices in the network with high accuracy. Since this capability was precluded to 802.15.4 devices due to the limited signal bandwidth, in March 2004 the IEEE 802.15 Low Rate Alternative PHY Task Group (TG4a) was created with the goal of defining alternative physical layers (PHYs) able to provide the desired ranging capability, and correspondingly adapting the medium access control (MAC) layer [4].

The principal interests of this group were in providing a standard with high-precision ranging capability (1 m accuracy and better), high aggregate throughput, and ultra low power consumption (mainly due to low transmit power levels, typically under –10 dBm), as well as adding scalability to data rates, longer range, and lower cost. Although support of ranging in 802.15.4a compliant devices is optional, the additional capabilities over the existing 802.15.4 standard are expected to enable significant new applications and market opportunities. Sensing and location mapping of disaster sites; precision agriculture, where soil moisture, pH levels, and pollutants can be sensed and problematic areas can be compartmentalized; location-based routing and data collection, where routing decisions are made based on actual physical location; as well as location tracking of moving objects are some of the applications the IEEE 802.15.4a standard is envisaged to support.

In March 2005 a baseline specification was approved by the TG4a committee, consisting of two optional PHYs: an ultra wideband (UWB) impulse radio (operating in the unlicensed UWB spectrum) and chirp spread spectrum (operating in the unlicensed 2.4 GHz spectrum). The committee completed the standardization of the alternate PHYs in January 2007, and in March of the same year the IEEE-SA Standards Board gave its final approval. With the 802.15.4a standard complete, semiconductor manufacturers are focusing on the production of the first integrated circuits (ICs) to implement the standard.

This article reviews the main features of the IEEE 802.15.4a standard, as well as the motivation behind the proposition of the two alternative physical layers, emphasizing how the unique characteristics of each PHY satisfy the requirements of the applications that drove their development.

THE ALTERNATIVE PHYS

It has become apparent that the high heterogeneity of application requirements could not be fulfilled with the exploitation of the original 802.15.4 PHY. Novel applications, such as connecting laptops to projectors, video distribution from set-top-boxes to TV systems, and music forwarding from player to headphones or speakers demand higher range and relatively high data rates that could only be supported with the adoption of the UWB impulse radio PHY operating

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[1] *ZigBee is built around the 802.15.4 MAC and PHY layer specifications, adding higher-layer enhancements.*

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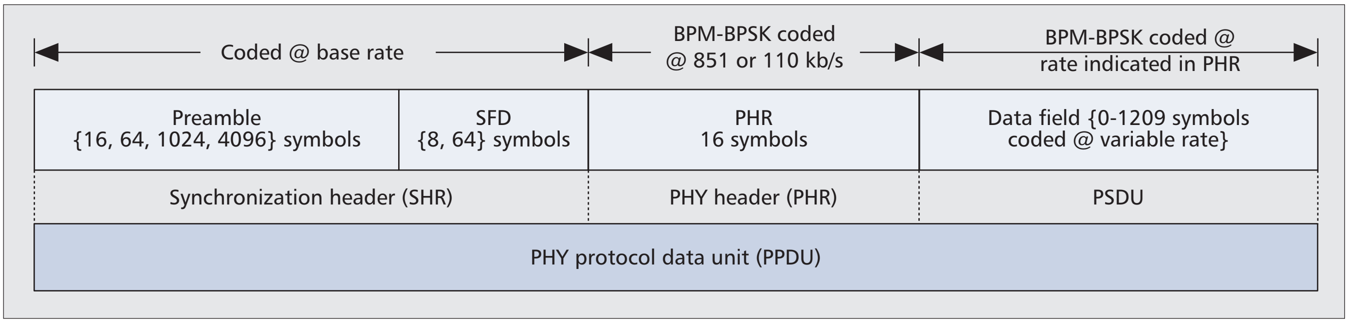

Figure 1. *UWB PHY frame structure.*

Property	Value	
PHY option	**UWB PHY**	**CSS PHY**
Frequency bands	250–750 MHz (sub-gigahertz) 3244–4742 MHz (low-band) 5944–10234 MHz (high-band)	2400–2483.5 MHz
Channels	16 channels	14 channels
Data rates	110 kb/s; 851 kb/s (nominal); 6.81 Mb/s; 27.24 Mb/s	1 Mb/s (nominal); 250 kb/s
Ranging support	Yes	No
Range	10–100 m	
Channel access	CSMA/CA or Aloha, as appropriate	

Table 1. *Summary of high-level characteristics.*

in the unlicensed UWB spectrum. In addition, the UWB PHY provides the optional feature of precision ranging, as mandated by currently deployed implementations such as medical imaging, rescue missions management, and other see-through-the-wall applications. While indoor localization systems do exist (ultrasound, infrared, and received signal strength indication [RSSI] measurements), they are expensive, hard to install and maintain, and have poor accuracy and resolution. In contrast, the very short time-domain pulses of UWB systems make them ideal candidates for combined communications and positioning, satisfying the application demands.

At the same time, however, other types of applications do not need the high throughput of the aforementioned ones, but instead require longer ranges and communications of devices moving at high speeds, such as moving vehicles monitoring, alarm systems for predicting vehicles' collision, and vehicle-to-vehicle communication. For these application types the chirp spread spectrum (CSS) PHY operating in the unlicensed 2450 MHz band was added. The CSS solution may also be used in the future for military applications as it is very difficult to detect and intercept when operating at low power. Collectively, both new PHYs added scalability to data rates, longer ranges, lower power consumption and precision ranging capabilities to the standard, thus meeting the requirements of the envisaged IEEE 802.15.4a applications.

One of the fundamental differences between the two PHYs is the operating frequency band. The UWB PHY specifies operation in three distinct bands; the sub-gigahertz band, the low band, and the high band. UWB devices in each band operate independent of the other band, while all three bands have different regulatory constraints in different regions of the world. On the other hand, the 2450 MHz PHY specifies operation in the 2.4 GHz industrial, scientific, and medical (ISM) band, which has nearly worldwide availability. The channel plan for the CSS PHY was chosen to be identical to that of IEEE 802.11 systems in order to enhance coexistence and deployability. Furthermore, the international availability of the 2.4 GHz band offers advantages in terms of larger markets and lower manufacturing costs.

A second distinguishing PHY characteristic of interest to network and application designers is the transmission rate. The CSS PHY provides a transmission rate of 1 Mb/s and optionally 250 kb/s, while the UWB PHY supports an over-the-air mandatory data rate of 851 kb/s with optional data rates of 110 kb/s, 6.81 Mb/s, and 27.24 Mb/s for its three bands. The various data rates are supported through the use of variable-length bursts (detailed later) and can be exploited to achieve a variety of different goals. For example, the low rate of the UWB PHY can be translated into better sensitivity and larger coverage area, thus reducing the number of nodes required to cover a given physical area, while the higher rate of the UWB PHY can be used to attain higher throughput, lower latency, or lower duty cycle. Some of the high-level characteristics of the 802.15.4a standard are summarized in Table 1.

THE UWB PHY

The UWB PHY waveform is based on an impulse radio signaling scheme using band-limited data pulses [5]. The UWB PHY supports three independent bands of operation: the sub-gigahertz band, which consists of a single channel (channel 0) and occupies the spectrum from 249.6 to 749.6 MHz; the low band, which consists of four channels {1:4} and occupies the spectrum from 3.1 to 4.8 GHz, and the high band, which consists of 11 channels {5:15} located within the 5.8–10.6 GHz band. A compliant device shall implement support for at least one of the mandatory channels (these are channels 0, 3, and 9 for sub-gigahertz, low, and high band, respectively). The UWB channels {4, 7, 11, 15} are all optional channels and are differentiated from other UWB channels by the larger bandwidth (> 500 MHz) of the transmitted signals. The larger bandwidth enables devices operating in these channels to transmit at a higher power (for fixed power spectral density [PSD] constraints), and thus they may achieve longer communication range. Additionally, the larger bandwidth pulses offer enhanced multipath resistance, while leading to more accurate range estimates.

Since the deployment area is likely to contain multiple types of wireless networks lying in the same frequency bands, the ability to relocate within the spectrum will be an important factor in network success. Accordingly, the standard includes the necessary hooks to implement dynamic channel selection within the operating band. In doing so, the PHY contains several lower-level functions, such as receiver energy detection (ED), link quality indication (LQI), and channel switching (in response to a prolonged outage), functions that enable channel assessment and frequency agility.

THE UWB FRAME FORMAT

In IEEE 802.15.4a networks, devices communicate using the packet format illustrated in Fig. 1. Each packet, or PHY protocol data unit (PPDU), contains a synchronization header (SHR) preamble, a PHY header (PHR), and a data field, or PHY service data unit (PSDU). The SHR preamble is composed of a (ranging) preamble and a start-of-frame delimiter (SFD). The SFD signals the end of the preamble and the beginning of the PHY header. As a result, it is used to establish frame timing; and its detection is important for accurate ranging counting. The UWB PHY supports a mandatory short SFD (8 symbols) for default and medium data rates, and an optional long SFD (64 symbols) for the nominal low data rate of 110 kb/s.

The number of symbols in the preamble are specified according to application requirements. There can be 16, 64, 1024, or 4096 symbols in the preamble, yielding different time durations for the SHR of the UWB frame. The longer lengths, 1024 and 4096, are preferred for non-coherent receivers to help them improve the signal-to-noise ratio (SNR) via processing gain. Each underlying symbol of the preamble uses a length 31 preamble code, or optionally 127. Each preamble code is a sequence of code symbols drawn from a ternary alphabet {–1,0,1} and are selected for use in the UWB PHY because of their perfect periodic autocorrelation properties. A compliant PHY does have to support two preamble codes, but needs to use only one mandatory preamble symbol length.

After creation of the SHR, the frame is appended to the PHR, whose length is 16 symbols. The PHR conveys information necessary for successful decoding of the packet to the receiver: the data rate used to transmit the PSDU, the duration of the current frame's preamble, and the length of the frame payload (0–1209 symbols). Typical packet sizes for sensor applications such as control of security, lighting, and air conditioning are expected to be on the order of several bytes, while more demanding applications with high address overhead, supported, for example, by mesh topologies, may require larger packet sizes. Additionally, six parity check bits are used to further protect the PHR against channel errors. Finally, the PSDU is sent at the information data rate indicated in the PHR. Due to the variability in the preamble code length (31 or 127) and the possible mean pulse repetition frequencies (PRFs), {15.6 MHz, 3.90 MHz, and 62.4 MHz}, there are several admissible data rates the UWB PHY can support {0.11, 0.85, 6.81, or 27.24 Mb/s}. A compliant device shall implement support for the mandatory data rate of 0.85 Mb/s.

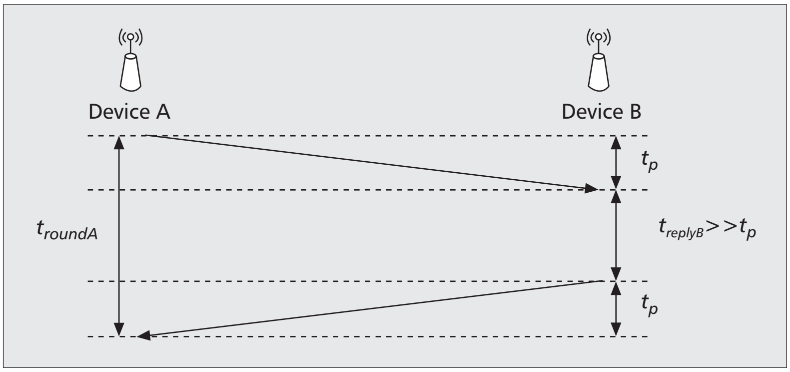

Figure 2. *Exchange of message in two-way ranging.*

MANAGEMENT OF PHY OPTIONS

A very rigid framework of option management rules governs the UWB PHY in a way that addresses a broad spectrum of applications and service conditions. Toward this, the specification of the UWB PHY includes a rich set of optional modes and operational configurations. These modes result from the list of available variables the UWB PHY allows to be implemented, including:

- Center frequencies
- Occupied bandwidth
- Mean PRFs
- Chip rates
- Data rates
- Preamble codes
- Preamble symbol lengths
- Forward error correction (FEC) options (i.e., no FEC, Reed-Solomon [RS] only, convolutional only, or RS with convolution)
- Waveforms (one mandatory and four optional pulse types)
- Optional use of clear channel assessment (CCA)
- Optional ranging (private or not)

The interoperability of compliant devices and the low-cost objective of this standard are ensured through the fact that only a small subset of the combinations of capabilities represent mandatory modes.

UWB PHY MODULATION

A combination of burst position modulation (BPM) and binary phase shift keying (BPSK) is used to support both coherent and non-coherent receivers using a common signaling scheme. The combined BPM-BPSK is used to modulate the symbols, with each symbol composed of an active burst of UWB pulses. The various data rates are supported through the use of variable-length

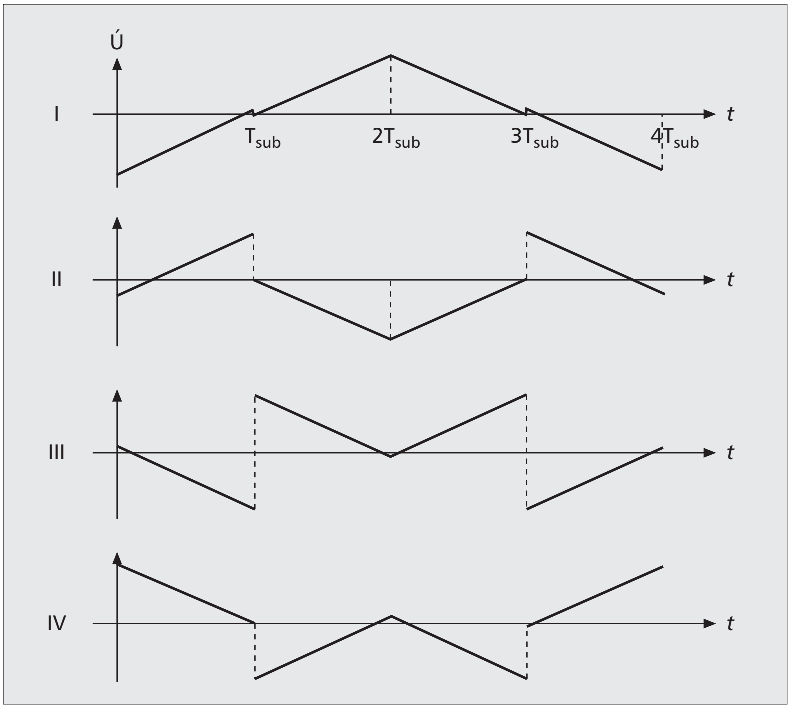

Figure 3. *Four different combinations of subchirps.*

bursts. In the BPM-BPSK modulation scheme, a UWB PHY symbol is capable of carrying two bits of information: one bit is used to determine the position of a burst of pulses, while an additional bit is used to modulate the phase (polarity) of this same burst.

RANGING

Ranging is an optional capability achieved through support of a number of specific PHY capabilities, as well as defined MAC behaviors and protocols. Only the UWB PHY supports ranging, although accurate ranging solutions based on chirp signals were proposed as well [6]. The mandatory ranging protocol is the two-way ranging (TWR) depicted in Fig. 2, which allows ranging measurements without the need for a common time reference. In this scheme ranging-capable device *A* (RDEV) begins the session by sending a range request packet to device *B*. Then device *B* waits a time $t_{\text{reply}B}$, known to both devices, to send a request back to device *A*. Based on that packet, device *A* can measure the round-trip time $t_{\text{round}A} = 2t_p + t_{\text{reply}B}$ and extract the one-way time-of-flight, t_p, with respect to its own reference time. The large bandwidth of the UWB signals enable accurate ranging estimations of less than 3 ns, which correspond to less than 1 m spatial uncertainty [7].

The packets used for ranging estimation are standard packets, with the only difference being the value of a specific bit in the PHR called the *ranging bit*, which is set by the transmitting PHY for frames used in ranging, and serves to signal the receiver that this particular frame is intended for ranging. A UWB frame with the ranging bit set in the PHR is called a ranging frame (RFRAME). There is nothing else beyond the ranging bit that makes an RFRAME unique. RFRAMEs can carry data, can be acknowledgments, and for the case of one-way ranging, RFRAMEs do not necessarily require an acknowledgment. Finally, the accuracy of each individual ranging measurement is carried from the PHY to the application with the ranging figure of merit (FoM).

In security-related sensor applications, the range information is a critical deliverable; however, it can be subject to hostile attacks. In order to safeguard the integrity of the ranging traffic, the IEEE 802.15.4a standard foresees a *private ranging* procedure, aimed at avoiding eavesdropping or jamming of ranging packets by malicious devices. The private ranging procedure is based on the use of dedicated longer preambles that guarantee higher security for the procedure.

CSS PHY

OVERVIEW

In addition to the UWB PHY, the standard also introduces an alternative solution based on the adoption of chirp signals. The CSS specification is designed to provide robust performance for low-rate wireless personal area network (LR-WPAN) applications while leveraging the unique capability of CSS waveforms to support long-range links or links to mobile devices moving at higher speeds. The chirp solution is intended to take advantage of the global deployability of the 2450 MHz band, due to favorable regulations, both indoors and outdoors, while offering enhanced robustness, range, and coexistence over wireless systems. This channel plan offers 14 channels spaced at 5 MHz. Since CSS can have a greater benefit from more spectrum, it does not use the narrower channels used by the 2450 MHz DSSS modulation. The supported data rates of the 2450 MHz CSS PHY are 1 Mb/s and optionally 250 kb/s. The two data rates are specified so as to offer implementers the flexibility to select the rate and properties best suited for their applications. For example, the lower rate would be appropriate in quiet additive white Gaussian noise (AWGN) and high multipath environments, while the higher rate would be appropriate for low-energy-consumption and burst interference environments.

CHIRP SYMBOLS

CSS is a spread spectrum system that is similar to both direct sequence spread spectrum (DSSS) and UWB, offering some significant properties in addition to these systems due to the different modulation methods. A *windowed chirp* is a sinusoidal signal whose frequency increases or decreases linearly over a certain amount of time. It could be thought of as sweeping the band at a very high speed. The type of CSS system defined for this standard uses patterns of smaller chirps, or *subchirps*, to build one larger chirp symbol. Figure 3 shows the four different sequences of subchirp signals that are available for use as time frequency diagrams. It can be seen that four subchirps, which have either a linear down-chirp characteristic or a linear up-chirp characteristic, and a center frequency, which has either a positive or negative frequency offset, are concatenated in order to construct a chirp symbol. Since each chirp symbol consists of four subchirps, the subchirp rate is four times higher than the chirp symbol rate.

CSS MODULATION AND SPREADING

This PHY solution uses CSS techniques to encode information, in combination with differential quadrature phase-shift keying (DQPSK) and 8-ary or 64-ary bi-orthogonal coding for the mandatory 1 Mb/s and 250 kb/s data rate, respectively. Unlike DSSS or FHSS, it does not add any pseudo-random elements to the signal to help distinguish it from noise on the channel. Instead, it relies on the linear nature of the chirp pulses. By using alternating time gaps in conjunction with sequences of chirp signals (subchirps), in different frequency subbands with different chirp directions, the CSS PHY provides subchirp sequence division as well as frequency division. The stream of DQPSK symbols shall then be modulated onto the stream of subchirps that is generated by the aforementioned chirp shift keying (CSK) generator, resulting in differential quadrature chirp shift keying (DQCSK) modulation.

THE CSS FRAME FORMAT

The PPDU packet structure of the CSS PHY is formatted as illustrated in Fig. 4. The PHR field in the chirp proposal is used to describe the length of the PSDU that may be up to 256 octets in length. Moreover, the preamble for the 1 Mb/s data rate consists of eight chirp symbols, and that of the optional 250 kb/s consists of a higher number of chirp symbols, equal to 20. For the two different data rates the CSS PHY also specifies different SFD bit sequences.

GENERAL RADIO SPECIFICATIONS

SENSITIVITY AND RANGE

In addition to meeting regional regulatory requirements, LR-WPAN devices must also meet several radio requirements. IEEE 802.15.4a currently specifies receiver sensitivities of –85 dBm or better for the 1 Mb/s case, and –91 dBm or better for the 250 kb/s option of the CSS PHY. Similar receiver sensitivities are specified for the UWB PHY as well. These values include sufficient margin to cover manufacturing tolerances as well as to permit very-low-cost implementation approaches.

Naturally, the achievable range will be a function of the receiver sensitivity and the transmission power as well. UWB devices have no minimum transmission power dictated by this standard. However, they should transmit at lower power when possible in order to reduce interference to other devices and systems. The maximum transmission power is limited by local regulatory bodies; in particular the FCC [8], which specifies that a receiver shall have a maximum input level greater than or equal to –45 dBm/MHz.

UWB BAND COEXISTENCE

LR-WPAN devices using UWB share the spectrum with other PHYs operating in unlicensed bands. For this reason, it is important that they provide good coexistence performance with respect to other systems using spectrum overlaid by the UWB bands. The UWB PHYs provide a number of extra coexistence features: low power spectral density (PSD) in accordance with regulations for UWB in different parts of the world, multiple bands and operating frequencies within each band to allow devices to avoid bands that might be in use or otherwise unavailable, and optional modes to operate with shorter symbol timing that minimize emissions and channel occupancy. Additionally, the higher optional bit rates of the alternative PHYs result in shorter *on* times for operation, enabling devices in close proximity to shorten their transmission duty cycle by as much as a factor of 32 relative to the mandatory rate, further reducing the likelihood that these devices might interfere with or will be subject to interference from other systems.

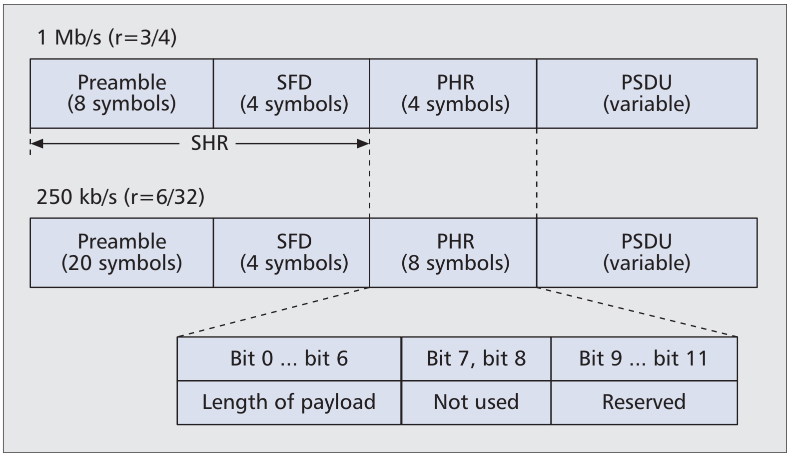

Figure 4. *Format of the CSS packet.*

THE MAC SUBLAYER

To begin with, there are partial modifications to the 802.15.4 MAC to support the proposed alternative PHYs. There will be an addition to the PHY data service access point (PD-SAP) primitive to include the choice of data rate to be used for the next packet, and some new PHY PAN information base (PIB) primitives to address ranging. In the next subsections we analyze the network topology and device definitions common to the two standards, as well as the medium access strategies, together with the new Aloha approach made possible by the UWB PHY.

NETWORK TOPOLOGIES

802.15.4a supports all types of devices and topologies defined by the IEEE 802.15.4 standard in its MAC section. The two classes of devices supported are full functional devices (FFDs), in which all network functionalities are implemented, and reduced functional devices (RFDs) that only support a reduced set of functionalities and are thus typical sensor nodes capable of measuring a physical parameter (i.e., temperature) and executing simple commands.

RFDs and FFDs organize themselves in personal area networks (PANs), with the adopted ad hoc PAN topology typically referred to as a *piconet*. The common configuration of a PAN will be a star topology, where the master node at the center of the star, the PAN coordinator, is responsible for coordinating the entire network. Devices in this scheme can only exchange information with the PAN coordinator as shown in

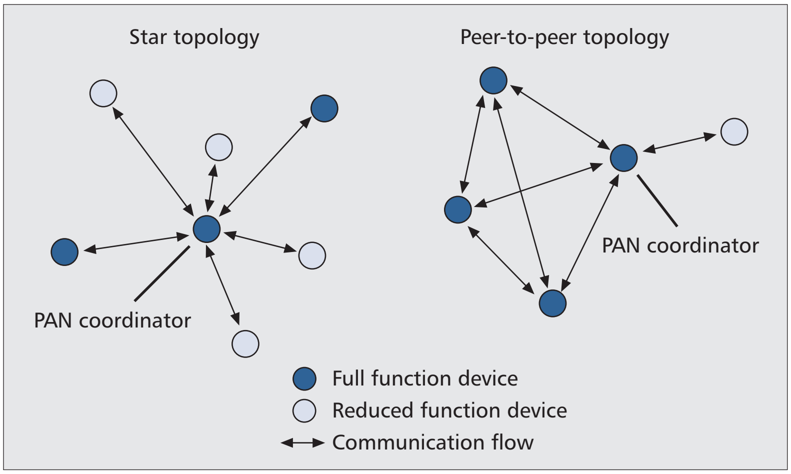

Figure 5. *Star and peer-to-peer networks [3].*

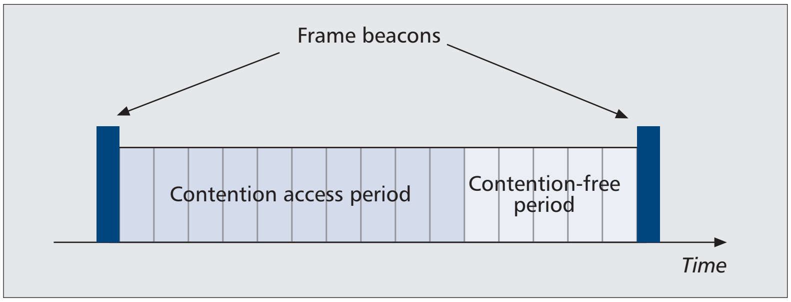

Figure 6. *Example of superframe in the beacon-enabled modality [3].*

Fig. 5. A PAN can also adopt a *peer-to-peer* topology, where FFD devices can communicate directly as long as they are within physical reach, while RFD devices, due to their limitations, can only connect with the PAN coordinator. The adopted topology is an application design choice; some applications, such as fire detection, may require the low-latency connection of the star network, while others, such as perimeter security, may require the large-area coverage of peer-to-peer networking.

MAC STRATEGIES

According to the IEEE 802.15.4/4a specification, access to the medium within a piconet can be either scheduled-based or contention-based (detailed later). In both cases medium access within a PAN is controlled by the PAN coordinator, which may choose between two different channel access modalities: *beacon-enabled* and *nonbeacon-enabled*. Within the latter modality, the PAN coordinator broadcasts a periodic beacon containing information related to PAN identification, synchronization, and the structure of the transmitted superframe. The period between two consecutive beacons defines a superframe, which is divided in 16 slots (Fig. 6). The first slot is always occupied by the beacon, while the other slots are used for data communication by means of random access, forming the so-called contention access period (CAP). The PAN coordinator may assign time slots to a single device requiring dedicated bandwidth or low-latency transmissions. These assigned time slots are called guaranteed time slots (GTS) and together form a contention-free period. The nonbeacon-enabled modality, on the other hand, is particularly suited for PANs adopting peer-to-peer topology, but can be adopted in a star network as well.

Depending on the network topology, devices adopt a carrier sense multiple access with collision avoidance (CSMA/CA) protocol to access the medium, either slotted or unslotted. In a beacon-enabled network, devices use the slotted version of the CSMA/CA protocol, while in networks without beacons, unslotted or standard CSMA/CA is used. A detailed overview of these aspects may be found in [9].

The 802.15.4a standard inherits the strategies described above, with a significant difference in the channel access mechanism; the contentionless Aloha channel access is adopted also. This decision was based on the multi-user interference (MUI) robustness guaranteed by the UWB PHY that enables the Aloha approach to provide satisfactory throughput in medium and lightly loaded networks, avoiding the additional access delay due to the collision avoidance phase. By this, application scenarios with relaxed throughput requirements (often measured in a few bytes per day), such as industrial control and monitoring of temperature, sound, vibration, pressure or pollutants, would benefit from the Aloha scheme. The CSMA/CA access was, however, kept as an option in order to address high-density and high-traffic scenarios, and to enable the use of the CSS PHY. To this extent, the CSMA/CA access scheme would likely find application in areas such as home automation and consumer electronics, healthcare utilities and traffic regulation, and military motivated applications such as battlefield surveillance as well as army deployment.

DATA TRANSFER MODEL

As a consequence, the three data transfer modes IEEE 802.15.4/4a identifies are modified accordingly.

Data Transfer to a Coordinator — When a device wishes to transfer data to a coordinator in a beacon-enabled PAN, it first listens for the network beacon in order to synchronize to the superframe structure. At the appropriate time, the device transmits its data frame, using slotted CSMA/CA or Aloha, as appropriate, to the coordinator. The coordinator may confirm the successful reception of the data by transmitting an optional acknowledgment frame. In a nonbeacon-enabled PAN, a device wishing to transfer data simply transmits its data frame, using unslotted CSMA/CA or Aloha, as appropriate, to the coordinator.

Data Transfer from a Coordinator — In a beacon-enabled PAN, when the coordinator has data pending for a device, it announces so in the network beacon. The interested device selects a free slot and sends a data request to the coordinator, indicating that it is ready to receive the data. Slotted CSMA/CA or Aloha, as appropriate, is adopted to send the request. When the coordinator receives the data request message, it selects a free slot and sends data using slotted CSMA/CA or Aloha, as appropriate. In a beaconless PAN, the coordinator stores the data for the appropriate device anticipating a request from it. A device may request the data by transmitting a MAC command frame, using unslotted CSMA/CA or Aloha, as appropriate, to its coordinator at an application-defined rate. If a message is pending, the coordinator transmits the data frame using unslotted CSMA/CA or Aloha, as appropriate, to the device. If a data frame is not pending, the coordinator indicates this fact either with an acknowledgment frame following the data request or in a data frame with a zero-length payload.

Peer-to-Peer Data Transfers — In a peer-to-peer topology, every device may communicate with every other device in its radio sphere of influence, without involving the PAN coordinator. In order to do this effectively, the devices wishing to communicate will need to either receive constantly or synchronize with each other. Once again, the device transmits its data using unslotted CSMA/CA or Aloha, as appropriate.

CONCLUSIONS

The IEEE 802.15.4a-2007 standard is a novel physical layer standard capable of satisfying an evolutionary set of industrial and consumer requirements for LR-WPAN communications, requiring precision ranging, extended communication range, and robustness against interference and mobility. With the standardization of the alternative physical layers complete, the focus is now on the upper protocol layers and application profiles. Several leading semiconductor manufacturers have already announced their first generation of ICs, a blueprint that would allow the industrial market to shift toward this standard solution in the years to come.

It is too soon to tell how successful the IEEE 802.15.4a standard will be once deployed in the real world. One thing is certain; its backward compatibility with the IEEE 802.15.4 standard and the provision of a wider variety of applications will be the key features for its penetration to the constantly evolving wireless world.

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ACKNOWLEDGMENT

This work was performed within the framework of the project PENED 2003 (Grant no. 636), co-financed by E.U.-European Social Fund (75 percent) and the Greek Ministry of Development-GSRT (25 percent).

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BIOGRAPHY

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