IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	**On-Ramp Wireless Dynamic Direct Sequence Spread Spectrum (D-DSSS) Proposal for 802.15.4g**
Date Submitted	1 May 2009
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Re:	Proposal for 802.15.4g
Abstract	Dynamic Direct Sequence Spread Spectrum (D-DSSS) Proposal Which Addresses Capacity and Range Limitations of Other 802.15.4 Physical Layers
Purpose	Support the preparation of proposals and initial drafting process
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1 *Overview*

1.1 *Smart Utility Network (15.4g) PAR Requirements addressed by D-DSSS*

D-DSSS addresses the following application requirements, described in the Smart Utility Network (15.4g) PAR:

"5.4 Purpose of Proposed Standard: To provide a global standard that facilitates very large scale process control applications such as the utility smart-grid network"

"5.5 Need for the Project: … Utility networking and very large scale industrial applications have requirements to keep infrastructure to a minimum, scale to millions of nodes across diverse geographical environments, and do so with carrier grade reliability. To reach every node in the network a Wireless Smart Metering Utility Network needs the capability to vary radio range while providing for high spectral reuse"

"8.1 Additional Explanatory Notes: (Item Number and Explanation)
5.5 Need for Project
… Smart Metering Utility Network requirements for complete ubiquity – communicating with all devices within a geographic territory – explicitly requires maximum range within existing local regulations.
Applications for Wireless Smart Metering Utility Network further intensify the need for maximum range as many devices are located sub-optimally. An example is Wireless Smart Metering Utility Network devices located in rural areas as at the end of electricity 'feeders' – where doubling range reduces cost by a factor of four as the area covered increases by the same factor.
… An example is electricity meters located in highly obstructed, high multipath locations with inflexible antenna orientation.

1.2 *General*

Smart Utility Networks (SUN) are large scale networks formed by simple, low cost devices, typically forming ad-hoc multi-hop networks covering potentially vast geographic areas. Some of the devices in the network are hard to reach and may require additional infrastructure to join the network, because they may not be able to connect to other nodes in the multi-hop network.

This document describes a wireless PHY optimized for link margin and related MAC extensions for the air interface to support home to grid aspects of the SUN, especially targeted to hard to reach meters that are distant from other nodes in the network. Better link margin may also allow fewer hops in the network, even a direct connection to the access point, reducing power consumption requirements for battery operated devices. These devices trade data rate for link margin.

D-DSSS meets the PAR requirements and the need for good link margin with high processing gain, that allows an improvement of link budget, reliability, and scalability in a manner that is compatible with regulations globally. D-DSSS also allows a bandwidth to be chosen which fits with local regulations, while increasing receiver sensitivity by dynamically adjusting spreading factor/processing gain as needed to maintain reliable communications.

The ability to dynamically adjust transmit power and spreading factor allows to minimize interference to other systems, because minimum power is used to close the link.

1.3 Purpose

This document describes the D-DSSS PHY specifications optimized for high processing gain, to support the SUN scope as described in the IEEE PAR (Project Authorization Request) approved by the IEEE Standards Association (see reference [1]). This proposal defines an amendment to IEEE 802.15.4 to address the Low Data Rate Wireless Smart Metering Utility Network requirements, defining an alternate PHY and associated MAC modifications needed to support its implementation.

This proposal is intended to offer a high link margin mode especially targeted for hard to reach meters and battery operated devices.

1.4 Scope

The scope of this document includes primarily the D-DSSS PHY. MAC specifications are included in support of the proposed PHY. Within this document, the term “PHY” means the D-DSSS PHY proposed.

2 References

1. https://mentor.ieee.org/802.15/file/08/15-08-0705-05-0nan-wnan-par.doc
2. http://standards.iso.org/ittf/PubliclyAvailableStandards/s020269_ISO_IEC_7498-1_1994(E).zip

3 Definitions

See next section

4 Acronyms, Abbreviations (and Definitions)

5 D-DSSS General Characteristics

Dynamic Direct Sequence Spread Spectrum (D-DSSS) is a proposed mode for the new physical layer that addresses range limitations of existing 802.15.4 physical layers and thus provides a needed alternative physical layer for the Smart Utility Network (SUN) for hard to reach meters and for battery operating devices. D-DSSS achieves its range benefit by employing much larger processing gain that is typically achieved by other designs. D-DSSS allows for a maximum processing gain of 21 dB or 128 chips per coding symbol which stands in contrast to the 15 or fewer chips per bit of current 802.15.4 PHYs. This translates into a typical receive sensitivity of -123dBm using a 1MHz bandwidth channel and assuming 6dB noise figure.

Note that this large amount of processing gain and low level sensitivity are not unique – GPS demodulators routinely acquire and demodulate signals that are at this level and even lower. WCDMA and other modem cellular data services use spreading factors in excess of 128.

Although it is envisioned that some MAC extensions will be required to support this physical layer, this PHY works with the existing interfaces. Thus, any routing protocols or application software that has been developed over many years will be equally as applicable to a system incorporating this particular PHY.

The processing gain is employed only as needed based on channel conditions. A link that requires less processing gain may select a 9 dB (8 chips per symbol) processing gain and transmit at higher data rates, which reduces the amount of time its radio is active and further reduce the power consumption of battery powered devices.

D-DSSS utilizes the existing beacon mechanism described in 802.15.4 and its contention access period (CAP) and contention free mechanism (CFP) to synchronize data transmission.

The beacon structure is also used to allow each node to select the correct transmit power and spreading factor based on the information received from the beacon.

This PHY can be used in conjunction with other DSSS modes that use lower processing gain.

6 *PHY Specification*

This section describes the PHY specification for a high processing gain direct sequence PHY and the functionality of the service interfaces.

6.1 *General requirements and definitions*

6.2 *Operating frequency range*

The D-DSSS is designed to operate over a variety of frequency bands.

6.3 *Channel assignment*

6.4 *Channel numbering*

6.5 *PPDU Format*

Each PPDU packet consists of the following basic components:

- A synchronization header (SHR), which allows a receiving device to synchronize and lock onto the bit stream
- A PHY header (PHR), which contains frame length information
- A variable length payload, which carries the MAC sublayer frame

The PPDU packet structure is shown in Figure 1.

Octets: variable	2	1		1			variable
Bits: variable	16	7	1	4	1	3	
Preamble	SFD	Frame Length	Extended Length	Upper Extended Address	Parity Check	Future	PSDU Includes FCS
SHR		PHR					PHY Payload

Figure 1. PPDU format.

6.5.1 Preamble field

The Preamble field is used by the receiver to obtain chip and symbol synchronization with an incoming message. The preamble also allows:

- Support channel power measurement at nodes so node can accurately power-control its transmitter
- Used for selection of minimum spreading factor required to close the uplink – very important for power consumption optimization and/or to allow for higher data rate transmission

The length of the preamble is shown in Table 1.

Processing gain (dB)	Length		Duration (us)
9	2 Octets	32 symbols	256
12	2 Octets	32 symbols	512
15	2 Octets	32 symbols	1,024
18	2 Octets	32 symbols	2,048
21	2 Octets	32 symbols	4,096

Table 1. Preamble length field.

6.5.2 SFD field

The SFD is a field indicating the end of the SHR and the start of the packet data.

6.5.3 Frame length field

6.5.4 PSDU field

6.6 Data rate

The data rate varies from 3.9kbps to 62.5kbps, according to the spreading factor and the bandwidth employed, as shown in Table 1.

Spreading factor	**Processing gain (dB)**	**Data rate (kbps)**
8	9	62.5
16	12	31.25
32	15	15.625
64	18	7.8125
128	21	3.90625

Table 2. Data rate.

The coordinator is configured to use the maximum spreading factor. This allows it for reaching all nodes in the network. The nodes dynamically calculate the required spreading factor based on the received downlink signal strength and set their transmitter to that level.

6.7 Modulation and spreading

The D-DSSS PHY uses D-BPSK modulation, similar to 802.15.4, section 6.6.

6.7.1 Reference modulator diagram

<same as 802.15.4, section 6.6.2.1)

6.7.2 Differential encoding

< same as 802.15.4, section 6.6.2.2)

6.7.3 Bit-to-chip mapping

D-DSSS uses ½ rate convolutional code.

6.7.4 BPSK modulation

The chip sequences are modulated onto the carrier using BPSK with Gaussian pulse shaping where a chip value of one corresponds to a positive pulse and a chip value of zero corresponds to a negative pulse. The chip rate is 1Mchip/s.

6.7.5 Pulse shape

Gaussian pulse shape is used for the transmission.

6.7.6 Chip transmission order.

7 MAC sublayer specification

The MAC sublayer handles all access to the physical radio channel and is responsible for the following:

- Generating network beacons if the device is a coordinator
- Synchronizing to network beacons
- Handling and maintaining the GTS mechanism

7.1 Network topology

7.2 Superframe structure

D-DSSS utilizes the use of a superframe structure, as described in 802.15.4, section 5.5.1, to allow each node to select the correct power and spreading factor based on the information contained in the beacon.

The format of the superframe is defined by the coordinator. The superframe is bounded by network beacons sent by the coordinator and is divided into equally sized slots, according to the constraints in 802.15.4 and EGTS extension. The beacon frame is transmitted in the first slot of each superframe. The beacons are used to synchronize the attached devices. Any device wishing to communicate during the contention access period (CAP) between two beacons competes with other devices using a slotted CSMA-CA mechanism. All transactions are completed by the time of the next network beacon.

For D-DSSS the PAN coordinator dedicates guaranteed time slots (GTSs) for the communication. The GTSs form the contention-free period (CFP), which always appears at the end of the active superframe starting at a slot boundary immediately following the CAP, as shown in Figure 2.

7.2.1 Data transfer model

Two types of data transfer transactions are used, according to 802.15.4, section 5.5.2. The first one is the data transfer to a coordinator in which a device transmits the data. The second transaction is the data transfer from a coordinator in which the device receives the data.

7.2.2 Data transfer to a coordinator

When a device wishes to transfer data to a coordinator in, it first listens for the network beacon. When the beacon is found, the device synchronizes to the superframe structure. At the appropriate time, the device transmits its data frame to the coordinator.

7.2.3 Data transfer from a coordinator

When the coordinator wishes to transfer data to a device, it indicates in the network beacon that the data message is pending. The device periodically listens to the network beacon and, if a message is pending, transmits a MAC command requesting the data. The coordinator acknowledges the successful reception of the data request by transmitting an acknowledgment frame. The pending data frame is then sent. The transaction is now complete. Upon successful completion of the data transaction, the message is removed from the list of pending messages in the beacon.

7.3 MAC Functional Descriptions

D-DSSS utilizes the contention free mechanisms for channel access, according to 802.15.4, section 7.5.2. Contention-free access is controlled entirely by the PAN coordinator through the use of GTSs. Channel scanning is used by a device to assess the current state of a channel (or channels), locate all beacons within its POS, or locate a particular beacon with which it has lost synchronization. Following a channel scan and suitable PAN identifier selection, an FFD can begin operating as the PAN coordinator. The mechanisms to allow devices to join or leave a PAN are defined in 802/15/4, section 7.5.3. The mechanisms to allow devices to acquire and maintain synchronization with a coordinator are described in 802.15.4, section 7.5.4. Synchronization on a beacon-enabled PAN is described after first explaining how a coordinator generates beacon frames. The mechanisms for allocating and deallocating a GTS are described in 802.15.4, section 7.5.7.

7.3.1 Superframe structure

A D-DSSS coordinator bounds its channel time using a superframe structure. A superframe is bounded by the transmission of a beacon frame. The active portion of each superframe is composed of three parts: a beacon, a CAP and a CFP. According to 802.15.4, section 7.5.1.1, the beacon shall be transmitted, without the use of CSMA, at the start of slot 0, and the CAP shall commence immediately following the beacon. The start of slot 0 is defined as the point at which the first symbol of the beacon PPDU is transmitted. The CFP follows immediately after the CAP and extends to the end of the active portion of the superframe. Any allocated GTSs shall be located within the CFP.