Overview of IEEE 802.15.4 Standard

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Abstract — *This paper presents the study and review of the IEEE 802.15.4 standard. In this paper we discuss the architecture of the wireless standard while also understanding the motivation for the standard and the applications of IEEE 802.15.4 based networks. We shall also review the main technical considerations of the 802.15.4 standard. Also, the paper describes the main functional features of IEEE 802.15.4.*
Keywords:- architecture, motivation, applications, technical considerations, functional features

I. Introduction

The IEEE 802.15.4 standard was introduced for applications whose design criteria are typically low complexity, low cost, low power consumption and low data rate wireless connectivity among inexpensive devices. We may say that this device is define for a low rate wireless personal area network (LR-WPAN) The IEEE 802.15.4 standard defines the physical layer (PHY) and the medium access control (MAC) sub layer specifications for low data rate wireless connectivity with mobile devices with no battery or having very less battery power consumption requirements that may typically operate in a the personal operating space (POS) of 10 meters. However, depending upon the application, increase in the POS while reducing the data rate may be an acceptable trade-off. IEEE 802.15.4 allows a maximum over-the-air data rate of 250 kbps. IEEE 802.15.4 standard was designed to operate in unlicensed radio frequency (RF) bands. Since unlicensed RF bands are not the same in all territories of the world, IEEE 802.15.4 employs three possible bands, at least one of which should be available in a given territory. The three bands are centred on the following frequencies: 868, 915 and 2400 MHz.

IEEE has two main methods of channel access: (i) Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) and (ii) Time Domain Multiple Access (TDMA) using synchronisation beacons and Guaranteed Time Slots (GTS). There are three types of Data transfer methods in IEEE 802.15.4: (i) Data transfer to a coordinator from a device (ii) Data transfer from a coordinator to a device and (iii) Data transfer between two peer devices. In IEEE 802.15.4 standard, a 16-bit Frame Check Sequence (FCS) is used to detect possible errors in the data packet received at the receiver. Each device in the network is required to have an unique address. The IEEE 802.15.4 standard uses two methods of addressing: (i) 16-bit short addressing and (ii) 64-bit extended addressing. The IEEE 802.15.4 network has nodes classified depending upon their role in the network. The node known to us are the PAN Co-ordinator, Local Co-ordinator and end device. These nodes are of two general device types i.e. Full function device (FFD) and Reduced function device (RFD).

The software architecture of IEEE 802.15.4 is organised on two levels: The Physical layer (PHY) and the MAC sub-layer along with the LLC sub-layer. The main functional features of IEEE 802.15.4 are (i) Channel Management which takes care of allocating channels, ensuring channel availability for transmission and protecting channels from nearby interfering transmissions. (ii) Device Management deals with how the IEEE 802.15.4 based network deals with the device joining and leaving the network (iii) Device addressing (iv) Data frames and acknowledgements (v) Data Transfer (vi) Beacon-enabled and non-beacon networking (vii) Routing and (viii) Security.

II. Technical Description Of IEEE 802.15.4

A. General Description

IEEE 802.15.4 standard defines the protocol and interconnection of devices via Radio Communication in a Personal Area Network (PAN). IEEE 802.15.4 is a standard for Low Rate Wireless Personal area Network (LR-WPAN) designed for applications that demand low data rates and less power consumption, Some of the characteristics of LR-WPAN are: (i) Maximum data rate of 250 kbps while other data rates of 40 kbps and 20 kbps are also used (ii) Star or Peer-to-peer (mesh) topologies are used for operation of the network (iii) 16 bit short addressing or 64 bit extended addressing used for addressing the nodal devices of the network (iv) Available channel access methods such as Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) and allocation of Guaranteed Time Slots (GTS's) (v) Fully acknowledged protocol for data transfer reliability (vi) Low power consumption (vii) Energy Detection (ED) (viii) Link quality indication (LQI) (ix) IEEE 802.15.4 standard employs 3 possible RF bands: 16 channels in the 2450 MHz band, 10 channels in the 915 MHz band and 1 channel in the 868 MHz band.

The 915 MHz and 868 MHz frequency bands offer advantages such as fewer users, less interference and less absorption and reflection. However, the 2450 MHz RF band is most widely used for various reason such as: (i) Worldwide availability for unlicensed use (ii) Higher data rate (250 kbps) and more channels (iii) Lower power consumption (since transmit/receive are on for a shorter time due to higher data rate (iv) RF band are more commonly understood and accepted in the market. Also, this RF band is used by Bluetooth and IEEE 802.11 standard.

The Energy Detection (ED) function of IEEE 802.15.4 is available for use by higher software layers to avoid interference between two or more radio communications i.e. to select the best frequency channel at initialization and, if possible, to adapt to a changing RF environment by selecting another channel if the current channel is busy or poses any sort of problems. The operating environment is also a deciding factor for the range of the radio transmission.

IEEE 802.15.4 may use any one of the following three modulation techniques: Binary Phase Shift Keying

(BPSK), Amplitude Shift Keying (ASK), and Offset Quadrature Phase Shift keying (O-QPSK)[7]

Freq. (MHz)	No. of channels	Modulation	Spreading Method
868-868.6	1	BPSK	Binary DSSS
902-928	10	BPSK	Binary DSSS
2400-2483.5	16	O-QPSK	16-array orthogonal

B. Operation frequencies and Data Rates

IEEE 802.15.4 has 3 frequency bands as on September 2006[7]. Most data communication techniques of 802.15.4 take advantage of spread spectrum systems. In case of IEEE 802.15.4 standard, the spread spectrum techniques know to us are the direct sequence spread spectrum (DSSS) or the parallel sequence spread spectrum (PSSS). The spread spectrum techniques are particularly used since they use the data signal manufacture a signal that is impervious to noise and interference[2]. template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

C. Device types and their roles

There are two types of devices in LR-WPAN: Full-function device (FFD) and Reduced function device (RFD). FFD can operate in three modes serving as Personal area network (PAN) coordinator, coordinator and device. RFDs are intended for extremely simple applications such as turning a switch on or off. FFDs are capable of communicating with other FFDs and RFDs, however, an RFD is capable of communication with another FFD but no RFD.

D. Network Topologies

Contingent upon the application requirement, the LR-WPAN may operate in two ways:

1) Star Topology:

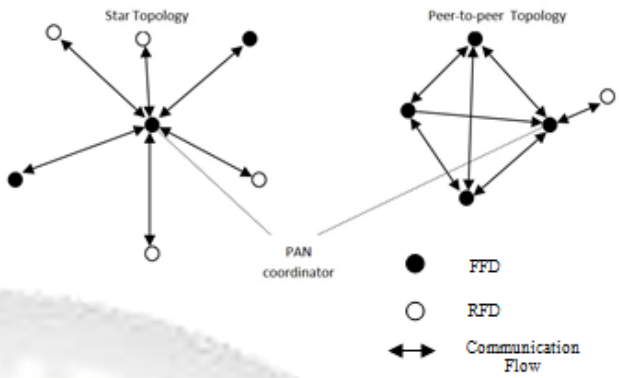
Every device in the network can communicate only with the PAN coordinator. PAN coordinator is the primary device of the PAN that is used to initiate, terminate or route the communication around the network.Once thfff

Application: Home automation, PC peripherals, toys and games, personal healthcare.

2) Peer-to-peer Topology:

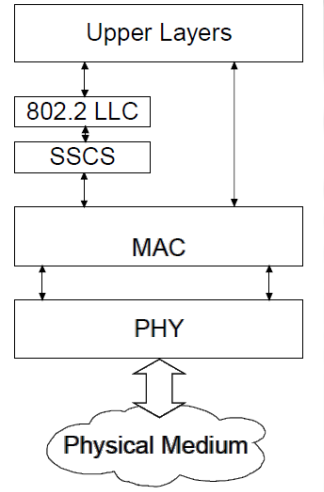
Each device can communicate directly with any other device within the POS range.

Application: Industrial control & monitoring, wireless sensor networks, intelligent agriculture, security, etc.



III. ARCHITECTURE

The IEEE 802.15.4 architecture is defined in terms of blocks called 'layers' where each layer is responsible for one part of the standard and offers services to higher layers.



Layout of the blocks is based on OSI model. Interfaces between the layers serve to define the logical links.

A. PHY layer specifications

IEEE 802.15.4 standard's PHY layer manages the radio channel and controls the packet data flow [an intro to IEEE]. The function of PHY layer is mainly known to be the interfacing to the physical transmission medium i.e. radio in this case, exchanging data bits within this medium and also exchanging data bits with the layer above. More specifically, the responsibilities of the PHY layer towards the physical radio medium include channel assessment and bit-level communications (i.e. bit modulation, bit demodulation, packet synchronization). The PHY layer provides the MAC sub-layer with the following two services: (i) PHY data service and (ii) PHY management service. The PHY data service The PHY data service enables PHY Protocol Data Unit (PPDU)transmission and reception across a radio channel while the PHY management services provides a mechanism to control radio communication settings and functionality from the MAC sub-layer. The PHY includes a management entitycalled the Physical Layer Management Entity (PLME) that can invoke PHY management functions. The PHY data service is accessedthrough the PHYData SAP (PD-SAP). The PHY management service isaccessed throughthe PLME-SAP. The

PLME also maintains the PHY PAN Information Base (PIB)[7]. The PHY layer is responsible for:

- Activating and deactivating the radio transceiver.
- Transmitting and receiving data
- Selection of the exact channel frequency for transceiver operation
- Perform ED
- Perform CCA
- Generate an LQI

1) Energy detection (ED) scan is a function used to avoid interference between radio communications. ED id used to select a suitable channel (normally, the quietest channel). The MAC requests the PHY to perform ED to which the PHY returns an 8 bit integer indicating the energy level in the frequency channel of interest. The energy level accuracy must be ±6dB or better [7].

2) Clear Channel Assessment: When transmitting a packet across a network without using Guaranteed Timeslots , the CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) mechanism is implemented to minimise the risk of a collision with another packet being transmitted in the same channel at the same time by another node. The transmitting node performs a Clear Channel Assessment (CCA) in which it first listens to the channel to detect whether the channel is alreadybusy. It does not transmit the packet if it detects activity in the channel, but tries again later after a random back-off period. A CCA is requested by the MAC sub-layer and is implemented by the PHY layer.

3) Linkquality indicator(LQI): LQI is an indicator of the quality of data packets received by the receiver. The received signal strength is a measure of the total energy of the received signal thus may be a used a s a measure of the signal quality. The signal to noise ratio (SNR) is also used to judge the signal quality i.e. Higher the SNR, lower are the chances of errors in the received data. Therefore, a signal with high SNR is considered a high quality signal. The LQI measurement is performed for each received packet and must have at least eight unique levels. The LQI is reported to the MAC layer and available to other layers for various analysis.

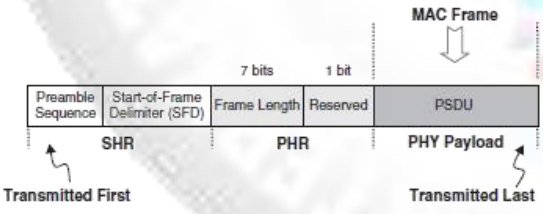


Figure PPDU Format

The PHY protocol data unit (PPDU) as seen in the figure consists of three components: Synchronisation header (SHR), The PHY header (PHR) and the PHY payload. The SHR allows the receiver to synchronize and lock into the bit stream. The PHR consists of the frame length information. The PHY payload is provided by upper layers and includes data or commands that need to be transmitted to another device.

B. MAC Sub-layer specifications

The MAC sub-layer provides an interface between the SSCS and the PHY layer. The MAC sub-layer conceptually includes a management entity called the MAC layer management entity (MLME) that provides the service interfaces through which layer management functions may be invoked. The MLME is also responsible for maintaining a MAC sub-layer PIB.channel of interest.

The MAC sub-layer provides two services, accessible via two SAPs: (i) MAC data service that is accessible via the MAC common part sub-layer (MCPS) data SAP (MCPS-SAP) and (ii) The MAC management service accessed via the MLME-SAP. MAC management service handles the responsibilities such as (a) Managing MAC PIB (b) MAC reset operation (c) device association and disassociation (d) Communication status indication (e) Enabling and disabling the receiver (f) GTS management (g) updating superframe configuration (h) Orphan notification (i) Channel scanning (j) Beacon notification (k) Synchronizing with a coordinator (l) requesting data from a Coordinator.

1) MAC Frame format:The general MAC frame consists of three sections as seen in the figure below:

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	variable	2
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Frame Payload	FCS
		Addressing fields						
MHR							MAC Payload	MFR

-General MAC frame format

The first field is the frame control that defines the frame type. Frame structure are of four types namely:

Beacon Frame: used by the coordinator to transmit beacons

2) Data Frames: used for all data transfers

3) Acknowledgement Frame: used for confirming successful frame reception

4) MAC command frame: used for handling all MAC peer entity control transfers

IEEE 802.15.4 standard uses 16-bit FCS based on International telecommunication Union (ITU) cyclic redundancy check (CRC) to detect possible errors in the data packet.

Thus we see that the responsibilities handled by the MAC layer may be summarised as generating beacons in case the device is a coordinator, synchronizing the device to the beacons in a beacon-enabled network, employing the CSMA-CA for channel access, providing a reliable link between two different devices, managing GTS channel access, providing PAN association and disassociation services and providing support for security.

IV. FUNCTIONAL FEATURES OF IEEE 802.15.4

A. Channel Management

IEEE 802.15.4 standard based network operates in either one of the three radio frequency bands of 868 MHz, 915 MHz and 2400 MHz having 1, 10 and 16 channel respectively. When a network is set up, the channel of operation within the relevant frequency band must be chosen. This is doneby the PAN Co-ordinator. IEEE 802.15.4 provides an Energy Detection Scan which can beused to select a suitable channel (normally the quietest channel). When a new device is introduced into a network, it must find the channel being used by the network. The new

device is supplied with the PAN ID of the network and performs either of the following scans:

- *Active Channel Scan* in which the device sends beacon requests to be detected by one or more Co-ordinators, which then send out a beacon in response
- *Passive Channel Scan* (beacon enabled networks only) in which the device listens for periodic beacons being transmitted by a Co-ordinator (the PAN Co-ordinator or, if in a Tree network, another Co-ordinator)

When a device loses communication with its Co-ordinator, in order to rejoin the network it performs an Orphan Channel Scan. This involves sending an orphan notification command over specific channels in the hope that its Co-ordinator will detect the broadcast and respond with a Co-ordinator Realignment command.

The MAC sub-layer performs these scans in response to requests from the next higher layer.

Clear channel assessment(CCA): As discussed above in Section III A.

Channel Rejection: In bands with more than one channel (915 MHz and 2400 MHz), in order to eliminate interference from other networks operating on nearby channels, IEEE 802.15.4 imposes a channel rejection scheme for the adjacent channel(s) and the alternate channel(s) (meaning two channels away). When receiving a signal:

- If another signal at the same level (0 dB difference) or weaker is detected in an adjacent channel, the adjacent channel's signal must be rejected.
- If another signal at most 30 dB stronger is detected from an alternate channel, the alternate channel's signal must be rejected.

The rest of the features namely Device management that includes PAN coordinator selection, device association and disassociation along with orphan devices have been discussed above. Also, other feature of IEEE 802.15.4 are device addressing, data frames and acknowledgements, Data transfer, Beacon and non-beacon enabled mode and security.

V. Conclusion

The IEEE 802.15.4 standard provides us with a network that is reliable, robust, less power consuming and cost effective. the networking techniques provide us with inexpensive data communication in a secure and economical for a low rate WPAN. We see the profit worthy feature of the standard such as ease of installation, lower data rate and lower power consumption which makes it a very good technique of communication where the communication range is limited by POS and the data rate is as good as 250 kbps over the unlicensed radio frequency bands.

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