Adaptability of IEEE 802.15.4(Zigbee) Protocol for Wireless Sensor network

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Summary

The IEEE 802.15.4/Zigbee protocol stack has been considered as a promising technology for Wireless Sensor Networks (WSN). IEEE 802.15.4 Low-Rate Wireless Personal Area Network (WPAN) standard specifies the lower protocol layers—the physical layer (PHY), and the media access control (MAC) portion of the data link layer (DLL) and Network layer(NWK) Wireless sensor network provide the low rate, wireless interconnection of ultra low cost sensor/actuator devices to enable the cyber world to sense and affect the real physical environment. The IEEE 802.15.4/Zigbee protocol stack provide selectable levels of security using AES-128 mechanism for privacy, sender authentication, message integrity. It uses fully handshake protocol for transfer reliability. In business applications where WSN are applied, failures in essential parts of the sensor network must be efficiently detected and automatically recovered. ZigBee is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking.This paper will analyze the adaptability features of IEEE802.15.4[3] at Physical, MAC and Network layer and various mode of operation at MAC layer.

Key Words:

Beacon mode, Orthogonal multilevel signaling, Constant envelop modulation, BLE mode, AODVjr Routing

1. Introduction

IEE802.15.4 is intended to be simpler and less expensive than other WPANs, such as Bluetooth. Networks can be built as either peer-to-peer or star networks. However, every network needs at least one FFD(Full function device)[6] to work as the coordinator of the network. topological restrictions may be added; the standard mentions the cluster tree as a structure which exploits the fact that an RFD(Reduced function device)[6] may only be associated with one FFD[6] at a time to form a network where RFD's[6] are exclusively leaves of a tree, and most of the nodes are FFD's[6]. The structure can be extended as a generic mesh[4] network whose nodes are cluster tree networks with a local coordinator for each cluster, in addition to the global coordinator. In most large network instances, the network will be a cluster of clusters. It can also form a mesh[4] or a single cluster. The current profiles derived from the ZigBee protocols support beacon[5] and non-beacon enabled networks.In non-beacon-enabled, an unslotted CSMA/CA channel access mechanism is used. In this type of network, ZigBee Routers typically have their receivers continuously active, requiring a more robust power supply. . Fault-tolerance is one of the main issues in WSNs since it becomes critical in real deployment environments where reliability and reduced inaccessibility times are important .

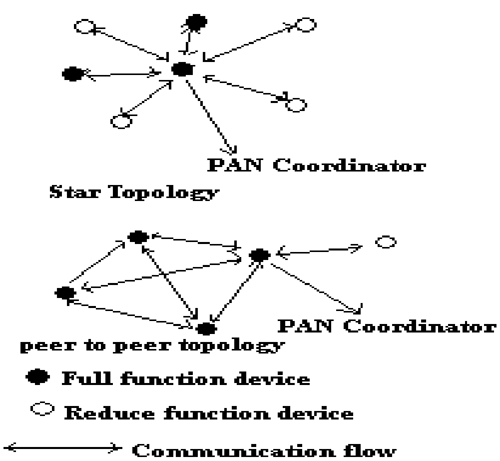


Fig :IEEE 802.15.4 Star and Peer to peer topology

2. Adaptability features at IEEE 802.15.4 PHY:

2.1 Constant Envelop modulation

A modulator connected to the terminal, the modulator configured to provide a constant envelope modulation for a signal, the signal being transmitted over the subscriber line in a second frequency band greater than the first frequency band, wherein the constant envelope modulation technique corresponds to a non-amplitude modulation technique and utilizes frequency modulation or phase modulation, whereby the constant envelope modulation technique is consistent enough so that intermodulation product distortion in the first frequency range does not interfere with voice communication in the first frequency band.

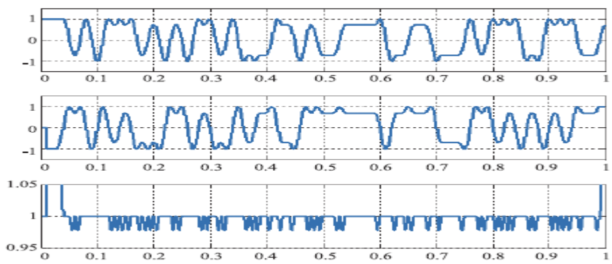


Fig: Fluctuations and slop representation

Since the envelope fluctuations are caused by the four waveforms mentioned above, it is hoped that we can modify the four waveforms to obtain constant envelope signals. In order not to affect the distribution of the power spectrum of modulated signal so that the power efficiency is enhanced while keeping the bandwidth efficiency, the modified waveforms must satisfy the following conditions:

1. The slope of the cross-correlator output wave form is continuous at their midpoints and at best continuous throughout their defining interval
2. All the waveforms should have zero slope at their endpoints and thus, concatenation of any pair of these will not result in a slope discontinuity
3. The energy differences of the waveforms should be as bigger as possible in order to guarantee the performance of demodulation.

Constant envelope offer not only enhanced spectral efficiency, they also provide an inherent transmitted power advantage. All constant envelope modulations allow a DS transmiter's power amplifiers to operate at or near saturation levels. On the other hand, standard BPSK, QPSK, QAM modulations contain AM components in the modulated envelope, which require from 3 to 6 dB of back off (from saturation) in the output power amplifier to reduce or eliminate spectrum splatter of sideband components that might cause Adjacent Channel Interference (ACI).Most non-constant envelope modulations actually require fully linear power amplification and thus for similar power outputs require RF power amplifiers that are up to 4 times more capable. These larger power amplifiers are less efficient, consume more primary power, generate more heat and are more expensive than their Class C amplifier counterparts.

2.2. No Duplex operation

Duplex systems are employed in many communications networks, either to allow for a communication "two-way street" between two connected parties or to provide a "reverse path" for the monitoring and remote adjustment of equipment in the field. Systems that do not need the duplex capability include broadcast systems, where one station transmits, and everyone else just "listens

2.3.Orthogonal multilevel Signaling:

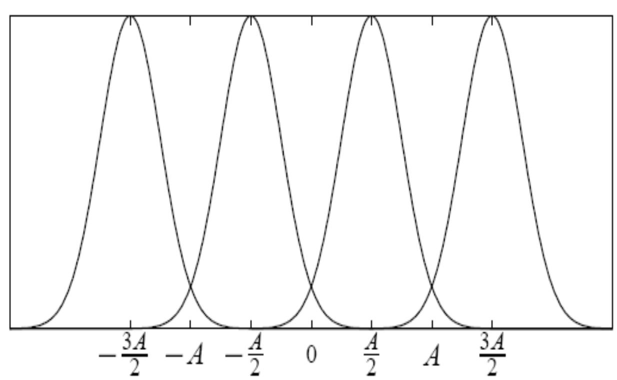
The bandwidth required for transmission of *binary* digital waveforms may be very large. In particular, for a channel of bandwidth B Hz the Nyquist rate is $1/T = 2B$ symbols per second. In the case of binary signaling each symbol carries one bit of information, so the information rate is limited to $2B$ bits per second. Clearly one can increase the information rate through a channel by increasing the bandwidth and the associated symbol rate. However, if the channel bandwidth is to remain fixed, then the only option is to increase the amount of information encoded in a symbol. If M is the number of distinct signal levels, then each symbol now carries log2 M bits of information, and the overall information rate rises to $2B$ log2 M. No additional bandwidth is required for this increase. The increased information rate comes either at the expense of added transmitter power, or an increased error rate at the receiver. Consider M amplitude levels centered on zero, with $M = 2^L$. If A is the spacing between levels, then the levels are at

$$A_j = \pm A/2;\ \pm 3A/2;\ \pm 5A/2;----(M-1)A/2$$

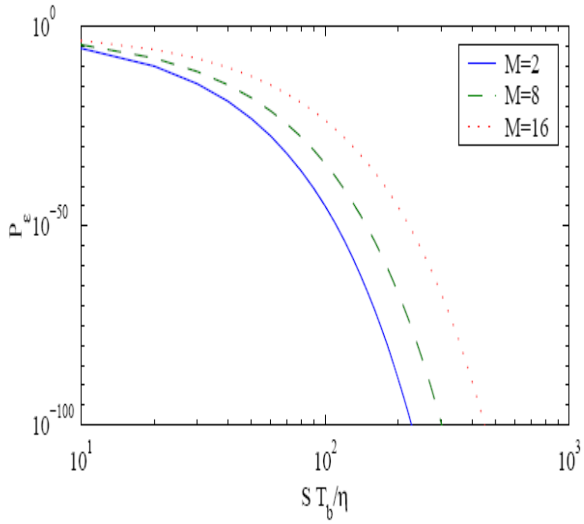
If all levels are equiprobable then the average signal power is

$$S=2/M\ \{(A/2)^2\ ,(3A/2)^2\ ,(5A/2)^2----((M-1)A/2)^2\}=\{(M^2-1)/3\}\{(A/2)^2\}$$

To maintain a constant spacing between levels, we therefore need to increase the transmitted power in proportion to the square of the number of levels. At the same time, the spacing between levels directly determines the error rate at the receiver. To see this, consider the case of $M = 4$: in the event of additive Gaussian noise the PDFs at the receiver will be as follows:



As before, for equiprobable symbols the optimal thresholds lie midway between the levels. It can be demonstrated that if there is no bandwidth constraint, then binary signaling has a lower error rate than *M*-ary signaling:



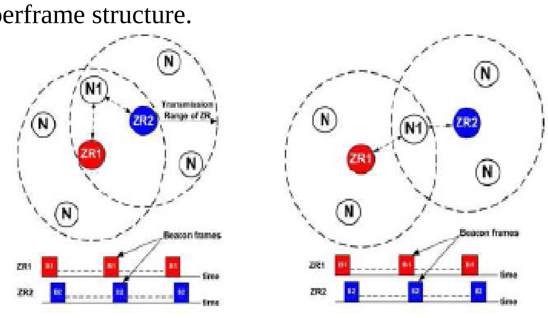
The main reason for using *M*-ary signaling is therefore when high information transfer rates are required over low bandwidth channels. *orthogonal M*-ary signaling can overcome this limitation. Here different signals are transmitted at different levels, with the difference being that the *shape* of the signals is also varied. This makes better use of available bandwidth, and error rates *decrease* as *M* increases. *M*-ary orthogonal signaling systems can approach the Shannon channel capacity as *M* tends to infinity. *M*-ary signals it is meaningful to talk about the **baud rate**, which is the number of symbols transmitted per second.

3. Adaptability features at IEEE 802.15.4 MAC:

Frames are the basic unit of data transport. A link quality indication (LQI) byte is attached to each received frame by the physical layer before it is sent to the medium access control layer. The receiving node expects to used this information for a number of purposes. It can be used as an indication of channel impairment, perhaps leading to the need to perform the dynamic channel selection process and move to another channel, It can also be used for power control of its own transmitter, under the assumption of a symmetrical channel. MAC basically operates in three modes due to this feature standard is adaptable to wireless sensor network

3.1 Beacon Mode

The IEEE802.15.4[3] MAC provides two modes of operation, the asynchronous beaconless and the synchronous beacon[5] enabled mode. The beaconless mode requires nodes to listen for other nodes' transmission all the time, which can drain battery power fast. The beacon[5] enabled mode is designed to support the transmission of beacon[5] packets between transmitter and receiver providing synchronization among nodes. In the beaconless mode, devices communicate asynchronously, requiring nodes to be continuously in receive mode, awaiting reception of data transmissions from other devices. Devices compete for channel access using an unslotted non-persistent CSMA/CA protocol. In the beacon[5] enabled mode, devices synchronize their actions and coordinate data transmission with each other. FFDs periodically transmit beacon[5] frames to synchronize wake up/sleep schedules with neighboring nodes. Channel access and data transmission are carried out using a superframe structure. The amount of energy spent in the MeshMAC idle mode increases compared to the beaconless mode. This is because the beaconless mode only switches between transmit and receive modes while the MeshMAC also switches its transceiver to idle mode during the inactive period to save more battery power. The main purpose of the beacon[5] is to synchronize devices in the network, to identify the PAN coordinator , and to describe the superframe structure.



a. Direct beacon frame collision   *b.* Indirect beacon frame collision

In a Multihop mesh[4] topology each neighbor can synchronize and send/receive data from any other neighbor, so in order to avoid direct and indirect collisions a device should not transmit beacons at the same time of any of its neighbors or its neighbor's neighbors. A number of proposals have been presented in the literature trying to achieve collision-free beacon [5]scheduling. Koubaa et. al. present a beacon scheduling algorithm for IEEE 802.15.4/Zigbee[2] Cluster-Tree Networks . The proposed approach, called Superframe Duration Scheduling (SDS), builds upon the requirement for beacon scheduling outlined in the Zigbee[2] specification for Cluster-Tree multi-hop topologies. The SDS algorithm defines a new beacon negotiation command packet that is encapsulated within a data frame.

3.2 Superframe Mode

The format of the superframe is decided by the PAN coordinator and is constructed from the Beacon Interval (BI)[12], which defines the time between two consecutive beacon frames, and the Superframe Duration (SD)[12], which defines the nodes' active period in the BI. The superframe duration provides a contention access period (CAP)[7] in which all devices use a slotted CSMA/CA protocol to gain access and compete for time slots, followed by a contention free period (CFP) for low latency applications which is divided in guaranteed time slots (GTSs) to be allocated by the PAN coordinator. In order to reduce energy consumption, the coordinator can introduce an inactive period by choosing BI > SD. The inactive period defines a time period during which all devices, coordinator included, go into a sleep mode. BI and SD are determined by two parameters, the Beacon Order (BO)[12] and the Superframe Order (SO)[11], respectively,

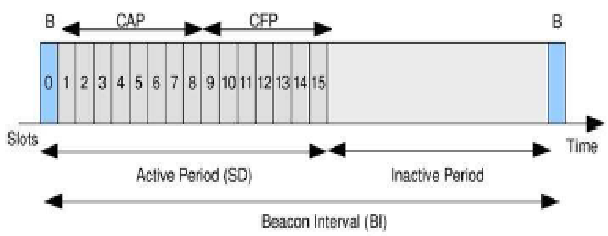


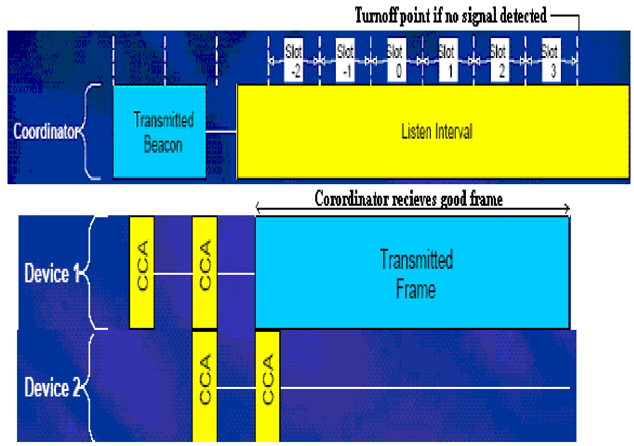
Fig :Superframe structure of IEEE82.15.4 in beacon enabled mode

BI = aBaseSuperframeDuration*2^{BO} **(1)**
SD = aBaseSuperframeSuration*2^{SO} **(2)**
for $0 \leq SO \leq BO \leq 14$
where aBaseSuperframeDuration = 15.36 ms (assuming 250 kbps in the 2.4 GHz frequency band) denotes the minimum duration of the superframe, corresponding to SO = 0.

The IEEE 802.15.5[3] Task Group 5 is discussing a proposal for beacon scheduling for mesh[4] topologies . The proposal involves making fundamental changes to the superframe structure of the IEEE802.15.4 MAC to provide a beacon-only period (BOP) in which beacons of neighbors and neighbors' neighbors will be transmitted. This proposal however involves changing the MAC superframe structure, which affects the interoperability with the current MAC standard.

3.3 BLE Mode

In conventional CSMA-CA most power consumption is due to the receiver, due to long monitoring periods required to support operation during high offered traffic period. IEEE802.15.4[3] supports a Battery Life Extension Mode (BLE)[8], in which the CSMA-CA backoff exponent is limited to the range 0-2. It greatly reduces receiver duty cycle in low offered traffic application.



Using BLE with n=14(beacon period =251.65824 s), total system duty (both Tx and Rx) can be less than 10ppm.

Channel access is contention based, via a carrier sense multiple access mechanism with collision avoidance (CSMA-CA); the beacon is followed by a contention access period (CAP)[7] for devices attempting to gain access to the channel. The length of the CAP[7] is adjustable as a fraction of the period between beacons. A "battery life extension"[8] mode limits the CAP[7] to a fixed time of approximately 2 ms. To address the needs of applications requiring low message latency, the standard supports the use of optional guaranteed time slots (GTS)[10], which reserve channel time for individual devices without the need to follow the CSMA-CA access mechanism. The IEEE 802.15.4[3] standard incorporates many features designed to minimize power consumption of the network nodes. In addition to the use of long beacon periods and the battery life extension[8] mode, the active period of a beaconing node can be reduced by powers of two, allowing the node to sleep between beacons.

4. Adaptability features at IEEE 802.15.4 NWK:

The main functions of IEEE802.15.4/ZigBee[2] network layer are forming network, allocating address for node joined the network, routing discover, routing contain There are three types of nodes: 1) The coordinator, which manages the network; 2) The routers, which are capable of participating in the AODV routing procedure; 3) The end devices, which transmit and receive frames through their parent node, end devices have no capability of AODV routing.

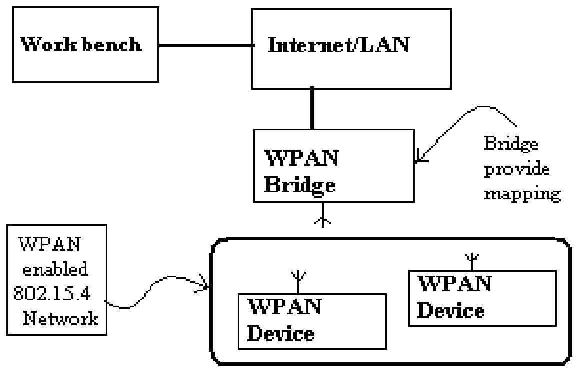


Fig: Basic network Architecture of WPAN

In order to achieve low cost and low power, IEEE802.15.4/Zigbee[2] routing algorithm combines Cluster-Tree and Ad-hoc On-demand Distance Vector routing (AODV). But the AODV[1] routing algorithm used by IEEE802.15.4/Zigbee[2] is different from classical AODV routing algorithm, it should be called AODV Junior (AODVjr) routing algorithm accurately

4.1 Network Address Allocate Mechanism

In IEEE802.15.4/Zigbee networks, the network addresses[9] are assigned using a hierarchical addressing scheme. The address is unique within a particular network and is given by a parent to its children. The IEEE802.15.4/Zigbee coordinator determines [C.sub.m] that is the maximum number of children a parent can have, [R.sub.m] that is the maximum number of routers a parent can have as children, and [L.sub.m] that is the maximum depth in the network. Cskip(d), the size of the address sub-block being distributed by each parent at depth d to its router-capable child devices.

4.2 AODVjr Routing Algorithm

AODVjr has main function of AODV and make some simplifications for reducing cost, energy saving and so on.

1) AODVjr[1] do not use sequence number in order to reduce control cost and simply routing progress. The sequence number used by AODV is to make sure that no cycle rode at any time. AODVjr formulate that the destination node can reply RREP when it has group. Even some inter node having routing to destination node can not reply RREP

2) AODVjr[1] do not have precursor list, In AODV, if node detects there is an interruption in next-hop link, it makes upper node send RERR to inform influence node. AODVjr did not have precursor list because RERR is only sent to node which send failure.

3) AODVjr[1] use local repair mechanism when link breaks. In the progress of repairing, it also dose not use sequence number but allow destination node to send RREP. Sending RERR to destination of data group and noticing that node no arrive if it repairs fail.

4) The node using AODV provides consistency information to other nodes by sending HELLO group periodically. The node using AODVjr dose not send HELLO group periodically, it updates neighbor list only according to receiving group or information provided by MAC.

IEEE802.15.4/Zigbee[2] Routing includes two types of node: RN+ and RN-. RN+ is a kind of node which has enough memory and be able to run AODVjr. RN- is contrary to RN+, it has neither enough memory nor ability of running AODVjr, so it has to process group by Cluster-Tree algorithm. IEEE802.15.4/Zigbee[2] routing allow RN+ to seek the best optimize link: RN+ start to use routing discover to find the shortest link to the destination node after it receives group, if there are two links have the same hop, node choose the better one according to the LQI which provides by MAC layer of IEEE802.15.4[3]; node deliver group via the link, if there is an interruption in the link, RN+ repair routing by local repair mechanism. AODVjr reduce the delay of group deliver and improve reliability of group deliver.

5. Conclusion and Further work

In this paper we analyzed the adaptability feature for specified layers of 802.15.4 PHY,MAC,NWK. Every layer had it's own specific work technique which basically aims to reduce the power consumption, delayed delivery etc. MAC layer has various mode of operation, structure and interoperability feature. IEEE802.15.4[3] is flexible enough to meet the need of various commercial application. It can also perform as a bed for power conservation research. The further work is expected for auto reconfiguration of coordinator, and failure recovery mechanism, research work should be intended towards Security enhancement techniques for sensor network of ultra low power.

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